RESEARCH AND DEVELOPMENT, TAX INCENTIVES,
AND THE STRUCTURE OF PRODUCTION AND FINANCING

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UNIVERSITY OF TORONTO PRESS

Toronto Buffalo London

Toronto Buffalo London
Printed in Canada

ISBN 0-8020-6629-1

Canadian Cataloguing in Publication Data

Bernstein, Jeffrey Ian, 1950-
Research and development, tax incentives, and the structure of production and financing

ISBN 0-8020-6629-1

1. Research and development tax credit.
2. Production functions (Economic theory).
3. Capital productivity. I. Title.

HD75.B47 1986 338.9 C86-094275-9

Contents

Acknowledgments

I would like to thank David Conklin of the Ontario Economic Council for his encouragement during the course of this study. The research has benefited from the comments and suggestions of Keith Acheson, John Evans, Lok Ho, Don McFetridge, M.I. Nadiri, two anonymous referees, and seminar participants at the Ontario Economic Council.

RESEARCH AND DEVELOPMENT, TAX INCENTIVES,

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1

Introduction

PURPOSE

The slowdown in productivity growth, persistently high rates of unemployment, and intense competition from foreign producers have generated a great deal of interest in the sources of output growth. It is generally recognized that technological change exerts a positive and significant influence on the ability of an economy to expand output. A major component of technological development is research and development (R&D) investment.

The significance of the sources of output growth in influencing industrial performance has led governments to introduce a wide variety of policies designed to affect R&D expenditures. The first purpose of this study is to estimate the effectiveness of the various R&D investment tax incentives. Specifically, three direct incentives are considered: the immediate expensing provision, the tax credit, and the special allowance.

Besides the direct incentives, indirect tax incentives also operate on R&D expenditures. For example, because investment in R&D and in plant and equipment may be related in production processes, tax policy designed to influence the latter may have an effect on R&D expenditures. In this study we estimate indirect effects on R&D investment. The two incentives considered are the accelerated depreciation provision and the tax credit on plant and equipment expenditures.

The second purpose of this study is to investigate the manner in which firms finance R&D projects relative to the method of financing investment in plant and equipment. The conventional wisdom is that R&D investment is generally financed by equity, whether through internally generated funds or share issues, rather than by debt. Indeed, it may

be that only firms generating a substantial flow of funds can support a sizeable R&D investment effort. The debt-financing composition of both plant and equipment and R&D investment is estimated in this study. Moreover, we evaluate the effects that changes in the interest rate on corporate bonds exert on the structure of production and R&D expenditures.

To identify the effectiveness of tax incentives and the influence of interest rates on R&D expenditures an econometric analysis of the structure of production and financing is conducted. Two significant features of the model are used in the analysis. First, the model is dynamic because we recognize that there are lags involved in completing R&D projects. In other words, R&D expenditures generate an accumulation of R&D capital. This accumulation involves an adjustment period in which corporations attain their desired stock of R&D or knowledge capital. Second, in the model the demand for R&D capital is determined simultaneously with the demands for labour and plant and equipment (or physical) capital. All production and investment decisions are interrelated. This allows us to investigate the interaction of R&D capital with labour requirements and physical capital utilization in production processes. Specifically the demand for R&D capital, like the demands for other inputs, depends on an array of factor prices and output quantities.

ORGANIZATION

The study is divided into a number of chapters. Chapter 2 provides a brief survey of the literature on R&D investment. The major focus of this literature has been the role of R&D investment as a source of productivity growth. Little, if any, emphasis has been placed on the determinants of R&D investment itself. In the present work, firms accumulate R&D investment into a type of capital input which, like physical capital associated with plant and equipment, is determined by factor prices and output production. This is one of the few studies conducted with Canadian data that investigates the determinants of the demand for R&D capital and the rate of R&D investment within the context of general production decisions.

Chapter 3 provides a brief overview of the institutional features of the relevant aspects of tax policy over the sample period for the study. In addition, we also discuss the major results from the literature concerning the effect

of tax incentives on the rate of physical investment. This is the first study to investigate the role of tax incentives in relation to the demand for R&D capital and its rate of investment.

Attention is drawn to the degree to which R&D investment tax credits are unutilized by Canadian firms whose sales are in excess of 50 million dollars. This is an important issue because these firms account for most R&D investment. They comprise our sample of firms. The underutilization of the R&D investment tax credits limits the effectiveness of this instrument in stimulating this type of investment. In order to measure the seriousness of the underutilization issue, we distinguish between the effective (or actual) and statutory R&D investment tax credit rates.

Chapter 3 contains calculations of the effect that alternative tax incentives exert on the unit cost of R&D expenditures. Moreover, the effect that recent policy initiatives would have on this cost is discussed.

Chapter 4 provides details for the data bank that was constructed for this study. Chapter 5 is a technical chapter, which covers the development of the theoretical model, the empirical specification, the estimation results, and a discussion of the adjustment process. The adjustment process relates to the speeds at which physical and R&D capital are accumulated by the firms in the sample. Here we analyse the length of time it takes for the firms to attain each of their desired capital stocks, and how the adjustment of one of the stocks affects the rate at which the other stock is accumulated.

The determinants of the factor demands are analysed in Chapter 6. In particular, the econometric results relating to the effects of changes in the input prices of physical capital, R&D capital, and labour on the structure of production are determined. In addition, we investigate the role of output production in determining the demands for physical and R&D capital and labour requirements. Indeed, the demand for R&D capital is responsive to changes in its own factor price and changes in output as well as to changes in the input prices of the other factors of production. Because of our special interest in the demand for R&D capital and the level of R&D expenditures, we calculate the effect of changing factor prices and output on current industrial R&D expenditures in Canada.

The tax-incentive effects are detailed in Chapter 7. Because changes in tax policy affect the unit cost of the

factors of production, and thereby the factor prices, we build on the role of these prices as determinants of the structure of production in order to determine the efficacy of tax policy. The effects of the physical and R&D investment tax credits and the incremental R&D investment allowance on factor demands and industrial R&D expenditures are analysed. We also calculate the costs to the government, in terms of lost tax revenue, of each of the policy initiatives, in order to find the additional R&D expenditures per dollar cost of the three policy instruments.

The financing issue is addressed in Chapter 8. Two features are discussed. The first relates to the financing composition used in the accumulation of physical and R&D capital. Second, the effect that changes in the corporate bond interest rate exert on the structure of production and industrial R&D expenditures is analysed. In Chapter 9 we provide a summary of the conclusions resulting from this study.

2

Research and development capital

The purposes of this chapter are to discuss the manner in which product and process development activities are integrated into the general set of production decisions and the measurement problems that arise in this context. With respect to the measurement problems we discuss the current statistical summaries pertaining to research and development expenditures and consider how they can be transformed in order to be incorporated into an analysis of production activities.

THE PRODUCTION PROCESS

The starting-point of the discussion is the production process of a firm. In general, an array of outputs are related to a group of inputs. Some of the products are the outcomes of activities designed to develop new products or processes. Moreover, many of the inputs are the factors involved in the 'idea generation' process. In fact what is usually observed is that product and process development is embedded in the general production structure of a firm.

It is important to realize that the efficiency of knowledge production activities depends on their relationship to other areas of the firm. On many occasions ideas have emerged that have not been utilized because their importance was not understood by the marketing and manufacturing departments. There are also instances where scientists and engineers have been unable to develop products or processes that could become operational.

Many different inputs are used in the creation of new products and processes. Generally, these inputs are scientists, engineers, technicians, laboratories, related equipment, and materials. The different factors of production are

usually combined in a single category called knowledge capital or R&D capital (see Griliches 1979).[1]

There are a number of features associated with the utilization and accumulation of R&D capital. First, the decrease in current production costs or the development of new products accompanying the increased utilization of the R&D capital input is the outcome of past R&D expenditures. The reason is that there are lags involved in R&D activities. A particular R&D project may take some years to complete. Once completed (and successful), the new product or process may not be introduced or implemented immediately. Moreover, process R&D activities may only be introduced gradually, thereby affecting only certain aspects of the firm's production cost structure. New products may only be introduced into specific locations that the corporation serves and not at once to all customers. The existence of the lags related to R&D activities implies that there is an adjustment process associated with production cost reductions and product variety expansions that can extend over several years.

Nadiri and Bitros (1980) found for firms operating in various U.S. industries that there is a significant adjustment process. Indeed, it may take from three to five years for firms to adjust their stock of R&D capital to the desired level. The adjustment period for R&D capital may even exceed the period for physical capital.[2]

Next, decreases in the cost of production brought about by the use of R&D capital lead firms to expand their output and alter the proportions of physical capital and labour utilized in the production process.[3] In the empirical literature on R&D capital accumulation the emphasis has traditionally centred around the output expansion effects. Griliches (1973) found for U.S. manufacturing industries an average R&D elasticity of output of 0.1. At the firm level, Griliches (1980) obtained a similar magnitude, although it was observed that for the firms whose outputs were relatively less R&D intensive the elasticity was 0.05. This set of

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1 The R&D capital input arises from the services of the R&D capital stock. The latter is the result of the accumulation of past R&D investment expenditures.

2 The physical capital stock consists of all equipment, structures, and land not used in R&D activities.

3 Intermediate inputs may also be included in this list. They are non-capital factors of production, such as materials, purchased from other firms.

results is consistent with those found by Mansfield (1968) for the U.S. chemical and petroleum products industry (0.12) and by Minasian (1969) for chemicals (0.11).

Recently, interest has moved to the factor substitution possibilities associated with the increase in the demand for R&D capital. Specifically, the issues centre on the degree to which R&D capital is used as a substitute or complement for labour requirements and physical capital utilization. Clearly, this is an important area of investigation for many groups in society, including the government. Bernstein and Nadiri (1984), dealing with four U.S. industries, have found that physical and R&D capital tend to be complementary factors, while each capital input is a substitute for labour.

One way to measure substitution possibilities is to investigate the manner in which the factors of production respond to changes in input prices. For example, the Bernstein-Nadiri result on the complementarity of the capital inputs implies that an increase in the factor price of physical capital leads to a decrease in the demand for R&D capital. Besides substitution possibilities, it is also possible to measure the effect of a change in a particular factor price on the demand for that specific input. For example, it is possible to estimate the effect of a change in the price of the R&D capital input on the demand for R&D capital.

Important policy conclusions could be drawn from the factor-price estimates. For example, tax credits and allowances on R&D expenditures serve to decrease the unit cost of these expenditures. By implication, the 'effective' price paid by firms for the use of R&D capital decreases. Thus tax policy changes operate through factor-price influences. Estimates of these influences are a necessary prerequisite to determining the effectiveness of government tax policy. Indeed, estimates of how changes in the input price of R&D capital affect the demand for R&D and physical capital and labour requirements would permit the analysis of the influence of R&D investment credits and allowances on the structure of production. We do not have, as yet, any such estimates for Canada, although Bernstein and Nadiri (1984) found that a 1 per cent increase in the factor price of R&D capital generated a 0.5 per cent decrease in the long-run demand for this factor.

MEASUREMENT OF R&D CAPITAL

There are two basic problems relating to the measurement of

R&D capital. The first pertains to the components of the input called R&D capital, and the second refers to its construction.

The components of R&D capital are derived from data on R&D expenditures, specifically data on scientific research and experimental development. These expenditures consist of the wages and salaries of scientists and engineers and the cost of laboratories and related equipment. R&D expenditures are generally classified into current and capital. Current expenditures are related to materials and wages and salaries. They comprise about 85 per cent of R&D expenditures. Capital expenditures relate to laboratories and equipment. Table 2.1 gives the breakdown of industrial R&D expenditures into current and capital.

R&D expenditures in Canada from 1971 to 1981 are presented in Table 2.2. Over the decade the expenditures in current dollars increased by about 223 per cent, while in 1971 dollars the increase was over 31 per cent. Notice that GERD (Gross Domestic Expenditure on R&D) in 1971 dollars did not increase monotonically over the decade. From 1971 to 1976, there was a slight decrease of about 1.5 per cent and then from 1976 to 1981 GERD in 1971 dollars increased by about 33 per cent. A pronounced decline in the proportion of GERD to GDP (Gross Domestic Product), or the average propensity to spend on R&D, is evident. The average propensity fell from a high in 1971 of 1.36 to a low in 1976 of 1.06. This amounted to a 22 per cent decrease. The average propensity began to increase in the last half of the decade, so that the decline over the whole decade was about 6 per cent.

The regional distribution of GERD is presented in Table 2.3. The distribution has been relatively stable. During the late 1970s Ontario accounted for half of all Canadian R&D expenditures, followed by Quebec and the Western provinces with 22 per cent each, and lastly the Atlantic provinces with 6 per cent. Within each region, over the late 1970s, there were some interesting variations in GERD as a percentage of Gross Provincial Expenditure (GPE). The Atlantic provinces showed a steady increase between 1977 and 1979. The percentage fell by 12 basis points in 1980, and then levelled off in 1981. Quebec exhibited a monotonically increasing percentage of GERD out of GPE. The situation for the Western provinces was similar, although there was a decrease in 1979. Ontario also had an increasing percentage over the last half of the 1970s. It was the region with the highest average. Moreover, in 1980 there was an increase of

TABLE 2.1
Industrial R&D expenditures in current and constant dollars

Year	Current dollars ($000,000) Current	Capital	Total	Constant 1971 dollars ($000,000) Current	Capital	Total
1971	401	63	464	401	63	464
1972	413	46	459	394	44	438
1973	460	42	503	401	37	438
1974	536	77	613	406	58	464
1975	631	69	700	431	47	478
1976	687	69	755	429	43	471
1977	786	70	857	458	41	499
1978	887	120	1,007	486	66	552
1979	1,077	192	1,269	535	95	630
1980	1,350	214	1,564	606	96	702
1981	1,730	274	2,004	704	112	816

SOURCE: Statistics Canada, *Standard Industrial R&D Tables 1963-1983*, Cat. Pub. SS83-3

13 basis points. Ontario has consistently been the major region in terms of both total R&D and average propensity.

The sectoral breakdown of R&D expenditures is presented in Table 2.4. We can observe that although the R&D expenditures of all sectors increased, those of the business sector grew most rapidly. The latter's share increased from 35 per cent in 1971 to 47 per cent in 1981. Business R&D expenditures can be disaggregated into mines and wells, manufacturing, and services. These figures are given in Table 2.5. Manufacturing represents the major proportion of industrial R&D, with 80 per cent in 1975 and 78 per cent in 1981. Mines and wells accounted for 7 per cent in 1975, but the proportion grew to 10 per cent in 1981. By 1981 mines and wells exhibited about the same percentage of industrial R&D as services. However, in 1975 services accounted for almost double the proportion of mines and wells.

The second measurement problem centres on the conversion of R&D expenditures into the R&D capital input. This factor of production could be constructed from data on the services

TABLE 2.2
Canadian R&D expenditures

Year	GERD current ($000,000)	Implicit price index*	GERD 1971 ($000,000)	GDP current ($000,000)	GERD/GDP
1971	1,315	100.0	1,315	96,961	1.36
1972	1,349	105.0	1,285	108,780	1.24
1973	1,448	114.6	1,299	128,164	1.13
1974	1,694	132.1	1,282	151,570	1.12
1975	1,910	146.3	1,306	170,681	1.12
1976	2,079	160.2	1,298	195,774	1.06
1977	2,326	171.5	1,356	215,066	1.08
1978	2,629	182.4	1,441	238,465	1.10
1979	2,988	201.3	1,484	265,912	1.12
1980	3,527	222.7	1,584	291,885	1.21
1981	4,244	246.3	1,723	331,338	1.28

*Relates to GNP.
SOURCE: Statistics Canada, *R&D Expenditures in Canada 1963-1983*, Cat. Pub. SS83-5

of the elements comprising R&D capital (such as scientists, engineers, and laboratories) and the rental rates for these services. If these data were available the knowledge capital input would be defined as the services provided by the knowledge capital stock. This definition is similar to one defining the labour input as the services provided by the labour force.

Little work has been done on the compilation of data from lease transactions, and as a consequence an alternative method of measurement is used. The approach we use is to compute the level of the knowledge capital stock at each point in time from data on R&D investment flows. The latter constitute the constant dollar R&D expenditures incurred in each year. The price index used to convert current dollar R&D expenditures into a constant dollar series could be constructed from data on the prices of the elements comprising the R&D expenditures. Using the contemporaneous R&D expenditures (the current and capital components) we can

TABLE 2.3
R&D expenditures by region*

Year	Region: Atlantic	Quebec	Ontario	Western	Canada
	($000,000)				
1977	123	451	1,046	410	2,050
1978	141	515	1,148	515	2,342
1979	182	591	1,321	581	2,689
1980	161	665	1,615	728	3,187
1981	179	812	1,934	905	3,864
	(% Canada)				
1977	6	22	51	20	100
1978	6	22	49	22	100
1979	7	22	49	22	100
1980	5	21	51	23	100
1981	5	21	50	23	100
	(% GPE)				
1977	0.99	0.89	1.25	0.61	0.96
1978	1.02	0.92	1.26	0.68	0.99
1979	1.13	0.95	1.29	0.65	0.99
1980	1.00	0.96	1.42	0.71	1.06
1981	0.96	1.04	1.49	0.78	1.12

*Pertains to Natural Sciences and Engineering.
SOURCE: Statistics Canada, *R&D Expenditures in Canada 1963-1983*, Cat. Pub. SS83-5

convert these expenditures to a constant dollar figure and then add the undepreciated portion of the existing stock of R&D capital. This procedure yields the current stock of R&D capital.[4]

4 R&D capital depreciates because its components consist of equipment, laboratories, materials, and the human capital associated with scientists and engineers. The depreciation relates to the physical use of the R&D capital; it

TABLE 2.4
R&D expenditures by sector

Sector	1971	1976	1981
Government			
$000,000	407	647	1,071
% total	31	31	25
Business			
$000,000	464	755	2,004
% total	35	36	47
Education			
$000,000	436	664	1,138
% total	33	32	27
Other			
$000,000	8	13	31
% total	1	1	1
Total			
$000,000	1,315	2,079	4,244

SOURCE: Statistics Canada, *R&D Expenditures in Canada 1963-1983*, Cat. Pub. SS83-5

TABLE 2.5
R&D expenditures by industry

Industry	1975	1978	1981
Mines and wells			
$000,000	47	56	205
% total	7	6	10
Manufacturing			
$000,000	561	791	1,556
% total	80	79	78
Services			
$000,000	92	160	243
% total	13	15	12
Total			
$000,000	700	1,007	2,004

SOURCE: Statistics Canada, *Standard Industrial R&D Tables, 1963-1983*, Cat. Pub. SS83-3

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does not pertain to the production of better products or processes (i.e., not to the evaporation of ideas). Also notice that all expenditures are capitalized and form part of the R&D capital stock. Thus we ignore the accounting artefact of current and capital expenditures.

An important difficulty in computing R&D capital centres on the spillovers associated with knowledge capital accumulation. Knowledge capital for any single firm does not depend solely on its R&D investment but also on the investment of other firms (which may or may not be in the same industry). The construction of an appropriate knowledge capital input must take into consideration the interaction between R&D investment levels of individual firms.[5] The problem, of course, is that firm interaction arising from R&D investment spillovers can extend over many industries and even countries. The analysis of production and investment decisions becomes quite complex because the technological linkages, as represented by the spillovers, must be included in the investigation. Thus spillover parameters must be estimated simultaneously with the whole host of price and quantity effects. The ability to undertake an exercise which involves potentially a large number of parameters may be severely hampered by the lack of data. For example, if there are 10 industries in a sample, then there would be 10 spillover parameters to estimate for each industry. These along with the other production-related parameters would generally exceed the number of observations. Because of the degree-of-freedom problem that arises, since spillovers cause the number of parameters to exceed the number of observations, assumptions must be made regarding the nature of the spillover links.

At this time we are only in the initial stages of determining empirically the array of R&D investment spillovers. Indeed, we have not even investigated most of the theoretical implications of the existence of these externalities. For example, firms operating in the same industry produce related products with similar technologies. Clearly, the R&D investments of these firms are mutually useful and can spill over. Estimates of the spillovers provide the intra-industry externality links. Although we are confronted with the degree-of-freedom problem, in this context, a solution would be to pool the firm data, thereby increasing the number of observations. Empirical work has only begun to investigate the extent and effects of intra- and inter-industry R&D spillovers on the structure of production and the incentive to conduct R&D investment.

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5 Spillovers refer to the phenomenon that a firm engaged in R&D activities may not be able to exclude others from freely obtaining the benefits of the R&D projects undertaken.

3

Tax policy and R&D expenditures

In major countries undertaking R&D investment, tax policy is an instrument used to stimulate such activity. However, it is difficult to find any assessment of their impact in affecting the structure of production and R&D expenditures. It is quite remarkable that there is very little direct quantitative evidence of the effect of various taxes and incentives on the demand for R&D capital (this point is not just endemic to Canada; see Collins 1982). The first purpose of this chapter is to detail the types of tax incentives that are relevant to R&D and the extent to which they have been utilized. The second purpose is to discuss how tax incentives have affected capital accumulation in general.

R&D TAX INCENTIVES

Over the years tax incentives relating to R&D investment have been altered by the federal government. Table 3.1 provides a brief description of the policy changes. We can observe from this table that the relevant tax incentives from 1975 were:

1 Current and capital R&D expenditures can be deducted in the year they are incurred or in any year thereafter.
2 Current and capital R&D expenditures in the current year are eligible for a tax credit. The tax credit rate is 25 per cent for companies eligible for the small-business corporate income tax rate, 20 per cent for corporations operating in the Gaspé area of Quebec and the Atlantic provinces, and 10 per cent for all other corporations. Deductible R&D expenditures are reduced by the amount of the credit. This credit is deductible in full against the first $15,000 of federal tax otherwise payable and in an amount up to 50 per cent of the remaining federal tax

otherwise payable. Unused credits can be carried forward for up to five years.

3 Current and capital R&D expenditures in the current year in excess of the average of the three preceding years are eligible for a 50 per cent tax allowance. Deductible R&D expenditures are reduced by the amount of the allowance.

The cost to the government of these three types of tax incentives is given in Table 3.2. The total of $205 million represents about 10 per cent of industrial R&D performed in 1982. The federal government provides about 85 per cent of the total support. The provincial governments share in the cost of the 100 per cent deduction and the 50 per cent incremental allowance, but this cost is offset by the tax credit they receive from the federal government. This offset occurs because the federal credit reduces the base for the purpose of calculating the 100 per cent deduction for provincial income taxes, which, in turn, increases both taxable income and provincial tax revenues.

Tax policy enables the private sector to take advantage of credits and allowances without having to enter into an interactive transaction with the government. The only constraint is that the tax authority must accept the expenditure as R&D. There is, however, some ambiguity as to what constitutes R&D, within the context of the current definition in the Income Tax Act. The difficulty arises, in part, because of the inevitable vagueness of any general, all encompassing definition. In addition, tax authorities may not have the necessary technical and scientific expertise to determine whether an activity properly qualified for the incentives. This shortcoming can be overcome by the use of properly trained individuals in the areas that are under contention.

To the extent that the tax authority's definition of R&D is vague, resources will be expended to convince the authority that particular expenditures should be subject to the appropriate credits and allowances. Hence the resource-saving resulting from the administrative ease of the tax policy is partly offset by the resource-use involved in having certain expenditures classified as R&D. For example, an expenditure must be 'wholly attributable' to scientific research and experimental development in order for it to qualify as a deduction for income tax purposes. The 'wholly attributable' characteristic biases the nature of the R&D performed, because unconventional applications of resources to R&D, although potentially profitable, may not be under-

TABLE 3.1
Brief history of Canadian R&D tax policy

Pre-1961	- Current expenditures on R&D were made wholly deductible in the year in which they occurred. - One-third of the capital expenditures on R&D during the year and the two preceding years were deductible in the current year. - The total deduction for R&D was not to exceed 5 per cent of the previous year's taxable income unless the expenditures were approved by the Department of National Revenue.
1961	- Capital expenditures were made fully deductible in the year incurred or any year thereafter.
1962	- Requirement for approval by authorities of expenditures in excess of 5 per cent of previous year's taxable income was eliminated. - 50 per cent of an increase in R&D expenditures (current or capital) over the base, defined as expenditures in 1961, was deductible from taxable income.
1967	- The 50 per cent deduction for all R&D expenditures in excess of the 1961 base was replaced by grants under the Industrial Research and Development Incentives Act (IRDIA). This act provided a cash grant of 25 per cent of capital expenditures and 25 per cent of current expenditures in excess of the average expenditures made during the base period. The latter period was defined as the five years preceding the grant year. The 25 per cent cash grant was non-taxable.
1975	- The deferral privilege for capital R&D expenditures was extended to current expenditures. Now both current and capital R&D expenditures could be written off in the year they were incurred or any year thereafter.
1976	- IRDIA repealed.
1977	- R&D investment tax credit introduced. The credits ranged from 5 to 10 per cent depending on the region. The credits were based on R&D expenditures. The 10 per cent credit was granted for the Atlantic provinces and the Gaspé area of Quebec.

1978	- R&D investment tax credits were doubled and a credit of 25 per cent for small businesses was introduced. - An additional tax allowance of 50 per cent of total R&D expenditures in excess over the previous three years was introduced.

TABLE 3.2
Government cost of R&D investment tax incentives for 1982

Incentive	Cost ($000,000) Federal government	Provincial government	Total
Deduction of 100 per cent of R&D expenditures	60	20	80
Tax credit	80	-15	65
50 per cent incremental allowance	45	15	60
Combined	185	20	205

SOURCE: *Research and Development, Tax Policies*, Department of Finance, April 1983, p. 5

taken by corporations. The tax authority may not consider them 'wholly attributable' to R&D.

The effectiveness of R&D tax incentives depends on whether or not a firm has any taxable income. A firm without taxable income will not benefit from the immediate write-off provision, the tax credit and allowance. A firm with taxable income, but not of sufficient magnitude to use all the deductions, credits, and allowances, faces a number of possibilities. First, if R&D expenditures msut be expensed in the current year and there are no provisions for transferring unused deductions, credit, and allowances, the firm will not benefit completely from the tax policy. Second, if current or capital expenditures can be deducted from taxable income at any time in the future, if capital expenditures must be amortized, if there are carry-back or carry-forward provisions, if unused deductions, credits, and allowances can be transferred, then tax policy benefits are enhanced.

These features differ by the flexibility they allow the R&D investor, and therefore each has distinctive allocative effects. For example, a firm which cannot use all of its

credits, in the absence of transferability, or carry-over provisions will not be able to take full advantage of the tax incentives (i.e., to enhance its cash flow position). The credits are not accepted as collateral in the financial capital markets. Table 3.3 provides information on the utilization of the tax incentives in 1980. First, we can observe that 31 per cent of R&D expenditures was incurred by firms who did not have sufficient taxable income to utilize the available benefits fully. In particular, they could not use any of the R&D investment tax credit. Second, 38 per cent of R&D was undertaken by firms who could not use all of their tax credits. Therefore, nearly 70 per cent of all R&D performers could not use all of their benefits.

The utilization of tax benefits varies across firms. Table 3.4 provides information on the distribution of firms by asset size and the degree to which tax incentives were not utilized in 1980. A number of implications emerge. First, most of the smaller firms are in the non-taxable category and consequently do not make any use of the tax incentives. Second, mid-size companies, although one-third of them are non-taxable, use most of their tax incentives. Tax incentives are most fully utilized in the $10-$49 million range. The problem is that this class accounts for only 10 per cent of industrial R&D. Third, the largest companies account for over 70 per cent of R&D, and only one-fifth of these fall into the non-taxable category, yet 60 per cent of their tax incentives are not utilized. The problem arises over the R&D investment tax credit, since only $15,000 could be claimed without limit, and thereafter in an amount up to 50 per cent of the federal income tax otherwise payable. Consequently, the larger firms hit the dollar constraint.

THE POST-TAX COST OF R&D EXPENDITURES

It is instructive to see how the three tax incentives affect the cost of R&D expenditures. The three incentives are the immediate deductibility, the credit, and the incremental allowance. First, suppose that an expenditure of $1 on R&D is incurred. This expenditure can be deducted from taxable income in the year it is made. Assuming there is taxable income and with a corporate tax rate u_c, the tax reduction is \$$u_c$ and the post-tax cost of the $1 of R&D expenditure is \$$(1-u_c)$. Hence, for example, with a corporate income tax rate of 0.46 the post-tax cost is $0.54 and the tax reduction is $0.46.

TABLE 3.3
Corporate tax status and R&D in 1980

	Per cent of R&D
Taxable companies	
No limits on tax credit	31
Limits on tax credit	38
Total	69
Non-taxable companies	
Profitable	19
Non-profitable	12
Total	31

SOURCE: *Research and Development, Tax Policies*, Department of Finance, April 1983, p. 15

TABLE 3.4
Company utilization of tax incentives in 1980

Size of Assets ($000,000)	Per cent of R&D by non-taxable firms	Per cent of unutilized incentives	Percent of R&D performed
<1	91	22	11
1-9	48	13	8
10-49	32	5	10
>50	20	60	71
Total	31	100	100

SOURCE: *Research and Development, Tax Policies*, Department of Finance, April 1983, p. 16

The effect of the immediate deductibility provision can be discerned by comparing the provision to one where only part of the R&D expenditures can be written-off against taxable income in the current year. Consider the $1 of R&D expenditure. Assume that the expenditure must be capitalized and depreciated at an annual rate of 30 per cent and the future depreciation deductions are discounted at 15 per cent. Thus the present value of the depreciation deductions is $0.67.[1] The tax reduction is $\$0.67u_c$ and the post-tax

1 The present value of depreciation deductions on $1 of R&D expenditures is calculated as

cost of the \$1 of R&D expenditure is $\$(1-0.67u_c)$. If u_c = 0.46 and there is taxable income, then the post-tax cost is \$0.69 and the tax reduction is \$0.31. The tax reduction is 33 per cent smaller than under the tax regime in which the \$1 of R&D expenditures can be immediately deducted against taxable income.

Next consider the tax credit on R&D expenditures. Suppose the credit rate is v. The tax reduction on \$1 of R&D expenditures is $\$(u_c(1-v) + v)$. One element in this expression is $\$u_c$, which reflects the \$1 of R&D expenditures. $\$u_c v$ is the amount by which the tax credit reduces the R&D expenditures that can be immediately deducted from taxable income. Hence $\$u_c(1-v)$ is the tax reduction from the deductibility provision. This must be added to the tax credit of \$v to yield the total tax reduction of $\$(u_c(1-v) + v)$. The post-tax cost of the \$1 is $\$[1 - (u_c(1-v) + v)]$. If $u_c = 0.46$, $v = 0.1$, then the tax reduction is \$0.51 with about \$0.065 attributable to the credit, and the post-tax cost of the \$1 is \$0.49. Notice the tax reduction is now greater than the post-tax cost of the R&D expenditure. The latter is less than half the pre-tax cost, which is \$1.

Third, consider the incremental allowance.[2] Suppose the excess of current R&D expenditures over the previous three years is \$1. This means that with an allowance rate of γ, current taxes will be reduced by $\$u_c\gamma$. However, the \$1 increase in R&D expenditures has the effect of decreasing the incremental allowance for the next three years by \$0.33 in each of the three years. With a discount rate of 15 per cent and assuming the income tax and incremental allowance rates are constant, the present value of the decrease

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$$\$1(0.3)/1.15) + \$(1-0.3)(0.3)/(1.15)^2 + \$(1-0.3)^2(0.3)/(1.15) + \ldots$$

$$= [\$1(0.3)/1.15][1/(1 - (0.7/1.15))] = \$0.67.$$

2 A credit on R&D expenditures reduces tax payments by some fraction v of the R&D expenditures. An allowance on R&D expenditures increases the deduction from taxable income by some γ of the R&D expenditure, and thereby the tax payments decline by $u_c\gamma$ of the R&D expenditures.

in the incremental allowance over the next three years is \$0.76 $u_c\gamma$. Thus the net tax reduction from the \$1 increase in R&D expenditures is $\$(u_c+0.24u_c\gamma)$ and the post-tax cost is $\$(1 - (u_c+0.24u_c\gamma))$. The tax reduction includes the immediate deduction of $\$u_c$ and the incremental allowance $\$0.24u_c\gamma$. If $u_c = 0.46$ and $\gamma = 0.5$ then the tax reduction is \$0.52, with about \$0.06 attributable to the incremental allowance, and the post-tax cost of the additional \$1 of R&D expenditures is \$0.48. Using the figures for the income tax, tax credit, and incremental allowance rates and combining all three incentives, the tax reduction is \$0.57 and the post-tax cost is \$0.43 on \$1 of R&D expenditures.

In Table 3.5 we present the post-tax cost of \$1 of R&D expenditures for the three possible tax credit rates of 0.10, 0.20, and 0.25 and the three income tax rates of 0.46, 0.40, and 0.25. Column 1 in the table relates to a discount rate of 15 per cent and column 2 to a 5 per cent discount rate. Clearly, a decrease in the discount rate increases the post-tax cost of \$1 of R&D expenditures. This effect operates through the incremental allowance. The decrease in the discount rate means that the future decline in the incremental allowance over the following three years, due to the \$1 of R&D expenditures in the present period, becomes larger. Thus the positive effect or the tax reduction in the current period due to the incremental allowance is offset by a larger negative effect or larger tax payment over the next three years.

The first two columns of Table 3.5 were calculated using the incentives operating in the pre April 1983 budget. This table was developed under the assumptions that there was sufficient taxable income to utilize all three incentives and that the level of R&D expenditures was such that all of the credit and the incremental allowance could be claimed. To the extent that these assumptions are not applicable, the post-tax cost of the \$1 of R&D expenditures would be greater than that reported in the table.

The post-tax cost of \$1 of R&D expenditures defines the effect of the tax incentives on the unit cost of undertaking R&D investment. However, the critical element in understanding the resource allocation implications of these tax incentives is the effect that the post-tax unit cost of R&D expenditures exerts on the demand for R&D capital. Once this link has been determined, the effect of alternative tax incentives on

TABLE 3.5
Post-tax cost of $1 of R&D expenditures

Company	Pre April 1983 budget 1	2	Post April 1983 budget 3
1. Large, non-manufacturing, non-Atlantic region	$0.431	$0.465	$0.431
2. Large, non-manufacturing, Atlantic region	$0.377	$0.411	$0.378
3. Large, manufacturing, non-Atlantic region	$0.492	$0.522	$0.480
4. Large, manufacturing, Atlantic region	$0.432	$0.462	$0.420
5. Small, any type, any region	$0.533	$0.551	$0.488

NOTES
Row 1, Col. 1 and 2: $u_c = 0.46$, $v = 0.10$, $\gamma = 0.50$; Row 1, Col. 3: $u_c = 0.46$, $v = 0.20$, $\gamma = 0.0$

Row 2, Col. 1 and 2: $u_c = 0.46$, $v = 0.20$, $\gamma = 0.50$; Row 2, Col. 3: $u_c = 0.46$, $v = 0.30$, $\gamma = 0.0$

Row 3, Col. 1 and 2: $u_c = 0.40$, $v = 0.10$, $\gamma = 0.50$; Row 3, Col. 3: $u_c = 0.40$, $v = 0.20$, $\gamma = 0.0$

Row 4, Col. 1 and 2: $u_c = 0.40$, $v = 0.20$, $\gamma = 0.50$; Row 4, Col. 3: $u_c = 0.40$, $v = 0.30$, $\gamma = 0.0$

Row 5, Col. 1 and 2: $u_c = 0.25$, $v = 0.25$, $\gamma = 0.50$; Row 5, Col. 3: $u_c = 0.25$, $v = 0.35$, $\gamma = 0.0$

Column 1 is calculated using a discount rate of 15 per cent and column 2 is calculated using a discount rate of 5 per cent. The formula for each row is $\$1 - \$[u_c(1-v) + v + \mu u_c\gamma]$, where $\mu = 0.24$ when the discount rate is 15 per cent and $\mu = 0.09$ when the discount rate is 5 per cent.

R&D expenditures can be discerned. Indeed, it is exactly in this way that this study differs from all others relating to tax incentives and R&D investment. We not only determine the

effect of the tax incentives on the post-tax unit cost of R&D investment, but we estimate the effect of this cost on the demand for R&D capital and the level of R&D expenditures. This estimate in turn permits us to determine the influence of the tax incentives.

Government policy on R&D investment has been changed in recent years with the adoption of a new set of tax incentives (see Department of Finance 1983). First, the tax allowance based on incremental R&D expenditures was eliminated. Second, with respect to the tax credit, the rates were increased to 35 per cent for companies eligible for the small-business corporate income tax rate, 30 per cent for companies operating in the Gaspé and Atlantic provinces, and 20 per cent for all other companies. In addition, the limitation on the extent to which the tax credit may be applied against federal taxes payable was removed, a three-year carry-back period was introduced, and the carry-forward period was increased to seven years.

In column 3 of Table 3.5, we present the post-tax cost of $1 of R&D expenditures. Clearly, when the discount rate is 15 per cent the post-tax costs under the two regimes are quite similar, because as the discount rate rises the net present value of the tax reduction from the incremental allowance increases and therefore the post-tax cost of R&D expenditures declines. The elimination of the incremental allowance is then just offset by the higher tax credit rate in the new regime (compare columns 1 and 3). When the discount rate is relatively low, the effect of the incremental allowance on the post-tax cost of R&D expenditures is relatively small. Hence the effect of the elimination of the incremental allowance is more than offset by the increase in the tax credit rate in the new regime (compare columns 1 and 3).

The post-tax cost of R&D expenditures computed in Table 3.5 is based on the assumption that all deductions, credits, and allowances could be fully utilized. However, because firms had inadequate taxable income or because of the level of their R&D expenditures not all of the tax incentives could be completely used (see Table 3.3). In recognition of the utilization problem the federal government introduced the scientific research tax credit (SRTC).[3] The SRTC provides

3 Another provision in the budget reflects the fact that under present tax policies the R&D investment tax credit does not provide an incentive to undertake knowledge investment if the firm has no tax liability against which

for a tax credit equal to 50 per cent of the value of debt or equity issued for the SRTC after September 1983.[4] The credit belongs to the first purchaser of the debt or equity (whether in the form of shares or royalty rights). The value of the equity or debt must equal the value of the SRTC. Corporations using the SRTC are liable for a tax equal to the amount of the tax credit made available to the debt or equity purchasers. The corporations, however, may eliminate the tax liability by renouncing the deductions and credits on the R&D investment financed through the SRTC mechanism in the current or immediately preceding year. For every dollar of R&D expenditures for which deductions and credits are renounced the tax liability is reduced by $0.50.[5]

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it can be applied in the current year or the five-year carry-forward period. A temporary measure has been proposed to alleviate this situation. The measure provides for a refund of a portion of the R&D investment tax credits earned between 19 April 1983 and 30 April 1986. The refund, for unincorporated businesses and businesses eligible for the small-business corporate income tax rate, is equal to 40 per cent of the value of credits which cannot be used to offset taxes in the year they are earned. For other corporations, the refund will be equal to 20 per cent.

4 If a purchaser of a share, whose funds are used to finance R&D investment, is entitled to receive an amount from a provincial government in respect of the share purchase, the consideration (or value) for which it was issued is reduced by this amount. Hence, the federal tax credit which is allowable to the share purchaser is reduced by the amount of any provincial credits received for the same consideration.

5 The SRTC is a replacement of two other instruments, the R&D limited partnerships (RDLP) and the scientific research investment contract (SRIC). The RDLPs were partnerships between financial investors and an R&D investment-undertaking firm. The deduction and credit were transferred pro-rata to the investors from the company. A problem with the RDLPs was that the ownership of the rights to the R&D investment was also transferred to the financial investors. The SRICs were contracts between a financial investor and an R&D investment-

The SRTC is an incentive to undertake R&D investment. This incentive can be used as an alternative to or in conjunction with the deductions and credits under the post April 1983 budget. A firm will use the mechanism that has the smaller post-tax cost associated with each \$1 of R&D expenditure. If a company raises \$1 under the SRTC the tax liability of the investor decreases by \$0.50 but the tax liability of the company increases by \$0.50. This liability can be eliminated by renouncing the deductions and credits that could be claimed on the \$1 of R&D expenditures. Thus the post-tax cost of \$1 of R&D expenditures under the SRTC mechanism is \$0.50.

We want to compare the cost under the SRTC with the post-tax cost of \$1 of R&D expenditures when the deductions and credits are used. First consider a company with insufficient taxable income to utilize any of the credits. The \$1 of R&D expenditures then costs the company $\$(1-u_c\theta)$, where θ is the proportion of the deduction that can be utilized. Now θ lies between 0 and 1. If $\theta = 0$, then none of the deduction can be used and the post-tax cost of the dollar of R&D expenditures is \$1, which is greater than under the SRTC. If $\theta = 1$, then all of the deduction can be used and the post-tax cost is $\$(1-u_c)$. Since the maximum corporate income tax rate is less than 0.5, then for all firms for which taxable income is not sufficient to allow the use of any credits (even if all deductions are utilized) the SRTC mechanism will be used to finance the R&D expenditures.[6]

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undertaking company. Under the contract the company performed the R&D investment as an agent of the investor, who paid for the R&D investment. Thus the investor would benefit from the deduction, credit, and allowance, since the investor would own the rights to the R&D investment. Therefore, there was a transfer of rights, as for the RDLPs, but not for the SRTCs. In addition, under the SRIC, the investor must have been in a business related to that of the company performing the R&D investment.

6 This analysis does not consider the cost of arranging the financing under the SRTC mechanism. If this brokerage cost is β per dollar of R&D expenditures then the firm will be indifferent to the SRTC and the immediate deduction provision when $\$0.50 + \$\beta = \$(1-u_c\theta)$. Thus the

Next consider a firm with sufficient taxable income to utilize all of its deductions and some proportion of its credits. Under the financing mechanism which relates to the use of deductions and credits, the post-tax cost of $1 of R&D expenditures under the post April 1983 budget is $(1-u_c)(1-v\eta)$, where η is the proportion of the credits that are utilized, and η must lie between 0 and 1. Any company will be indifferent between the two financing mechanisms when the post-tax cost of R&D expenditures for the two is the same. Thus $\$0.50 = \$(1-u_c)(1-v\eta)$. Given values of the corporate income tax and credit rates, the pivotal values of η can be obtained. These are presented in Table 3.6.

From Table 3.6 we can observe that if a large non-manufacturing company operating in any region of Canada except the Atlantic region utilizes more than 37 per cent of its R&D investment tax credits, then the company will not use the SRTC mechanism. Notice that a small business with sufficient taxable income to utilize all of its deductions must still use 95 per cent of its credits before it ceases to use the SRTC financing mechanism. The calculation of the pivotal value of the proportion of the R&D investment tax credit that is utilized depends on the income tax and tax credit rates. Indeed, as the income tax and tax credit rates increase the pivotal value decreases, since the post-tax cost of $1 of R&D expenditures (using the deductions and credits) decreases. Thus by implication, the SRTC financing

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pivotal value of θ is $\$(0.50-\beta)/u_c$. If $u_c = 0.46$, then for values of β of \$0.05, \$0.15, and \$0.25, the pivotal values of θ are 0.978, 0.761, and 0.544. If θ is greater than any of these pivotal values the SRTC mechanism will not be used. Notice that there is an inverse relation between the brokerage costs and the proportion of the deduction that can be utilized, for any corporate income tax rate. Also notice that as the corporate income tax rate decreases (e.g., from 0.46 to 0.25 for small businesses) the brokerage fees can dramatically rise per dollar of R&D expenditure before the company attains a sufficiently large proportion of the deduction to be able to utilize it. Indeed with $u_c = 0.25$ and θ equated to 0.978, 0.761, and 0.544 the respective values of β are 0.256, 0.310, and 0.364, which are substantially higher than under a corporate income tax rate of $u_c = 0.46$.

TABLE 3.6
Pivotal values of the proportion of R&D investment tax credit utilized

Company	Pivotal value of η*
1. Large, non-manufacturing, non-Atlantic region; $u_c = 0.46$, $v = 0.20$	0.370
2. Large, non-manufacturing, Atlantic region; $u_c = 0.46$, $v = 0.30$	0.247
3. Large, manufacturing, non-Atlantic region; $u_c = 0.40$, $v = 0.20$	0.833
4. Large, manufacturing, Atlantic region; $u_c = 0.40$, $v = 0.30$	0.556
5. Small, any type, any region; $u_c = 0.25$, $v = 0.35$	0.952

*$\eta = (0.5-u_c)/v(1-u_c)$.

mechanism becomes more expensive when the rate of credit utilization is smaller.[7]

ASSESSING TAX INCENTIVES ON INVESTMENT

In this study our aim is to compute the post-tax cost of a dollar of R&D expenditures using the actual rates at which deductions, credits, and allowances are utilized and then to discern the relationship between this cost and the demand for R&D capital and other factors of production. We would then be able to evaluate the effects of alternative tax incentives on the post-tax cost of a dollar of R&D expenditures and, in turn, on the level of R&D expenditures.

7 The pivotal value of the rate of credit utilization is affected by any brokerage fees which must be incurred in the use of the SRTC mechanism. There is an inverse relation between the pivotal credit utilization rate and the brokerage cost of financing $1 of R&D investment. As brokerage fees increase, the credit utilization rate at which the SRTC mechanism becomes relatively more expensive decreases.

Moreover, we would like to discern the effects on the demand for physical capital and labour requirements.[8]

Since there is no quantitative evidence of the effect of tax incentives on the demand for R&D capital, analogies to physical capital are often made. There are essentially two specific means (through tax policy) by which the government influences physical capital investment: tax credits and accelerated depreciation. The tax credit operates in the same manner as the one applicable to R&D investment. In addition, expensing all R&D expenditures, irrespective of whether they are current or capital, is a form of accelerated depreciation - with a depreciation rate for tax purposes equal to unity. However, the depreciation rate for tax purposes on plant and equipment capital is less than unity. Thus the post-tax cost of $1 devoted to physical investment is greater than that of $1 devoted to R&D investment.[9]

Studies of the effects of tax incentives on plant and equipment investment have found that there is a stimulating influence, but estimates differ as to the size and permanence. Hall and Jorgenson (1967, 1971) estimated for the United States that during 1962-70 the tax credit increased physical capital investment by about $3 billion (1965 dollars) per year, and accelerated depreciation caused a $1 billion (1965 dollars) per year increase. Bischoff (1971), in a somewhat different specification of the production process than the one employed by Hall and Jorgenson, found that the tax credit increased equipment expenditures by about $2 billion (1958 dollars) per year in the mid 1960s, but accelerated depreciation only generated $0.7 billion (1958 dollars) in equipment investment.

Lastly, Coen (1971), introducing a form of adjustment costs, found that both the tax credit and accelerated depreciation had almost no influence on plant and equipment expenditures. Thus, as Eisner and Nadiri (1968) have noted, the effects of the tax incentives depend on the specification of the technology, the type of physical capital, and

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8 Physical investment pertains to the accumulation of land, equipment, and structures which are not related to R&D. Physical investment is the major type undertaken by most firms.

9 See the discussion in the first section of this chapter pertaining to the deduction of all R&D expenditures as opposed to capitalization of some portion of these expenditures.

the nature of the adjustment process. Indeed, in the present study we specify both the technology and adjustment costs in terms of flexible functional forms, thereby permitting various degrees of factor substitution and speeds of adjustment.

Besides the analogy arguments that may (or may not) be made concerning the tax incentives on physical and knowledge capital, there is another reason for studying the effects of tax policy on physical capital investment. Investment in plant and equipment also affects the rate at which new technology is introduced, since many kinds of technological advances cannot be applied unless they are accompanied by physical capital expansion. It may be that in certain circumstances physical and knowledge capital are complementary factors. In such cases tax policy that stimulates the demand for plant and equipment also has an indirect effect on the demand for R&D capital. Evidence of this relationship has been known since the mid 1960s (see Schmookler 1966).

It is often not recognized that investment in R&D also affects the rate at which plant and equipment expansion occurs. If a firm is undertaking knowledge capital growth, it may be that more physical capital is needed in the new process or to produce the new product. As a consequence tax incentives that directly influence the rate of knowledge investment indirectly affect the plant and equipment growth rate. Hence there is a two-way relationship between the investment rates for both types of capital. In the present study we estimate the relationship between the capital demands and thereby measure the complete set of indirect and direct effects associated with changes in the tax incentives.

4

The data bank

The data-gathering process involved a rather detailed and complex set of steps. First, we were interested in corporate data, in order to obtain disaggregated information on the determinants of factor demands and the effectiveness of tax incentives. Thus the sample consists of a pooled set of cross-section and time-series data.

The second task was concerned with the selection of the corporations for consideration in the study. The criteria for selection centred around a number of characteristics. The companies had to be private-sector public corporations, they had to incur their own R&D expenditures in Canada (although they could be either Canadian-owned or foreign subsidiaries), they had to sell their products in Canada (they could also, of course, export), and finally their sales had to be $50 million or greater.

The legal status and sectoral criteria were chosen because financial reports are readily available for public corporations so that a complete data set could be developed for each corporation. Firms with sales of $50 million or more were selected because large firms tend to have more data collected on their activities. More important, however, because we are pooling time-series and cross-section data, and since there is an inadequate span of time-series data to permit testing of the manner in which the various firms might be combined, we wanted to have some homogeneity across firms. Using sales size (in this case $50 million or greater) is a generally acceptable technique (see Nadiri and Bitros 1980). However, in the present context the restriction on sales size is quite weak because only the lower bound is constrained.

We are concerned with firms operating in Canada. Hence we require that any firm in the sample must sell some of its output, as well as undertake its R&D projects in Canada. For

TABLE 4.1
Sample of companies

Company	1981 R&D expenditures ($000,000)	SIC
1. Electrohome Limited	3.8	61
2. Polysar Limited	n.a.*	26
3. Sherritt Gordon Mines Limited	5.6	42
4. Aluminum Co. of Canada Ltd.	41.4	42
5. Bombardier Limited	n.a.	53
6. Canadian International Paper Co.	n.a.	33
7. Northern Telecom Ltd.	264.0	63
8. Macmillan Bloedel Ltd.	17.4	33
9. Inco Limited	22.2	42
10. Cominco Ltd.	n.a.	11
11. Canada Wire and Cable Ltd.	n.a.	61
12. Steel Co. of Canada Ltd.	9.9	41
13. Consolidated-Bathurst Inc.	3.2	33
14. Canada Packers Inc.	5.1	21
15. Canadian General Electric Co. Ltd.	2.3	61
16. Imperial Oil Limited	5.6	24
17. Union Carbide Canada Limited	n.a.	26
18. Du Pont Canada Inc.	10.1	26
19. Dominion Engineering Works Ltd.	n.a.	51
20. Uniroyal Ltd.	n.a.	22
21. International Harvester Co. of Canada	n.a.	51
22. Fiberglass Canada Ltd.	5.2	71
23. General Goods Limited	6.0	21
24. Westinghouse Canada Limited	n.a.	61
25. Honeywell Limited	6.2	62
26. RCA Ltd.	n.a.	63
27. Texaco Canada Inc.	n.a.	24

*n.a. signifies not available from the survey.
SOURCE: Financial Post R&D Survey

our purposes these criteria define as tightly as necessary the concept of Canadian operations. It turns out that the characteristics of our sample tend to be complementary. Large firms are generally public corporations which sell their products and undertake R&D in Canada. The list of firms, their R&D expenditures in 1981, and their two-digit standard industrial classification (SIC) codes are presented in Table 4.1. The sample consists of 27 firms for the period 1975-80.

TABLE 4.2
Percentage of industrial R&D expenditures by top performers

Year	Top 10	Top 25	Top 50	Top 100
1973	35.2	50.5	64.0	76.7
1975	40.0	50.8	64.1	75.7
1977	36.1	52.5	65.7	78.1
1979	37.8	53.6	66.8	79.7
1981	38.7	56.5	69.9	81.8

SOURCE: Ministry of State for Science and Technology, *Science Notes*, Fall 1982, p. 7

TABLE 4.3
Variables

No.	Name	Source*
1	Sales, products	C, H1
2	Sales, services	C, H9
3	Salaries and wages	C, G12
4	Employee benefits	C, G14
5	P&E investment tax credit	C, K38
6	Net fixed assets	C, E21
7	Total depreciation assets	C, E19
8	Depreciation and amortization expense	C, G23
9	Net long-term debt	C, F23
10	Intramural R&D current exp. (wages and salaries)	R, 301-6
11	Intramural R&D current exp. (other current)	R, 307-12
12	Intramural R&D capital exp. (land)	R, 313-18
13	Intramural R&D capital exp. (bldg.)	R, 319-24
14	Intramural R&D capital exp. (mach.)	R, 325-30
15	R&D investment tax credit	R, 917-22
16	Wage index	A
17	Producer price index	A
18	Equity rate of return	N
19	Bond interest rate	N
20	R&D deflator	N
21	P&E deflator	A
22	Statutory corporate income tax rate	O
23	Capital cost allowance	C, J15
24	Present value of capital cost allowance	D
25	P&E expenditures	D
26	P&E investment	D
27	P&E average age	D

TABLE 4.3 (concluded)

Variables No.	Name	Source*
28	R&D investment	D
29	Output	D
30	Average rate of growth of output	D
31	R&D capital stock	D
32	P&E capital stock	D
33	Labour input	D
34	R&D tax allowance	D
35	P&E rental rate	D
36	R&D rental rate	D

*C represents CALURA Databank and the following designation shows the position.
R represents R&D Databank of Statistics Canada and the following designation shows the position.
D represents derived.
A represents the CANSIM Databank.
N represents the NBER R&D Databank.
O represents other.

Over the sample period the chosen companies accounted for over 50 per cent of industrial R&D expenditures in Canada. We have already noted in Table 3.4 the concentration of industrial R&D expenditures in firms with sales in excess of $50 million, which perform over 70 per cent of industrial R&D investment. In Table 4.2 we present the concentration of industrial R&D expenditures by the top performers as a percentage of the total. The top 25 firms accounted for about 53 per cent of these expenditures over the period 1975-80.

The variables needed in the model for each firm are the quantity and price of labour services, physical capital, and R&D capital services, and the quantity of output. In most cases these data had to be obtained and derived from various sources.[1] Table 4.3 lists the variables obtained for each firm and their source.

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1 We did not use materials as an input. The reason is that we did not have sufficient degrees of freedom when we estimated the model with materials as a factor of production (see Chapter 5 for discussion of the specification and estimation of the model).

Finding and deriving the data for each firm was a demanding task. A number of problems arose. First, the Corporations and Labour Unions Returns Act (CALURA) records have changed over time; also some gaps appeared in these records in the early 1970s. These two problems were solved by defining the time series as 1975-80.

A third problem centred on the fact that R&D expenditure data are collected by Statistics Canada on a company basis. Thus, although output or sales data may be obtained on an establishment basis, data for R&D expenditures cannot. From the CALURA records we were able to obtain sales on a company basis, which matched the form in which R&D expenditures were collected. Clearly, sales aggregation implies that a multiproduct firm is being treated as a single-product entity. If, in fact, the technologies of the various products are sufficiently segmented or if their prices change relatively by the same proportion then product aggregation is feasible. Unfortunately we did not have sufficient time-series data on each firm to test if product aggregation was warranted or, for that matter, to treat each firm as an entity producing two or more products.

Alternatively, we could have attempted to obtain output data on an establishment basis and then assign portions of R&D expenditures to each establishment. This approach does not seem to be appropriate because it presupposes that parts of R&D expenditures can be causally related to the output (or outputs) of each establishment, which, in general, cannot be done. R&D investment usually relates jointly to the outputs of a number of establishments. Moreover, even where a specific R&D investment relates to a particular product, we did not have the detailed information to establish the fact.

A fourth problem centred on the fact that a company may select certain subsidiaries under which to undertake R&D investment, while the parent or some other subsidiary may be the major source of sales. In these situations the legal enterprises were aggregated into a single economic entity by defining both the sales and R&D expenditures (for example) as pertaining to a single firm. Thus, if different subsidiaries carried out R&D investment we aggregated the expenditures. With the variables that we consider in this study there was no problem with double counting. Specifically, for R&D expenditures we consider those for each firm which are

intramural.[2] Any transactions between subsidiaries would always be counted once because only the R&D expenditures of the performers are added.

The R&D data tape of Statistics Canada was the source of the R&D expenditures, tax credits, and other R&D-related variables. Thus, besides the difficulty of developing such a large consistent set of data at the firm level, there was the task of merging two different data tapes. The two other sources of data were: the CANSIM tapes for the two-digit wage and producer price indexes; and the National Bureau of Economic Research for the equity rate of return, the bond interest rate, and the R&D deflator (see Cummins, Hall, and Laderman 1982).

We now describe the manner in which variables 24-36 listed in Table 4.3 were derived. The formulas used to calculate the variables are given in Table 4.4. First, using the average equity rate of return and the average capital cost allowance over the sample, the present value of the capital cost allowance (variable 24) was computed. Second, from the net fixed assets and depreciation, we arrived at plant and equipment (P&E) expenditures (variable 25). P&E investment (variable 26) was obtained by dividing variable 25 by the price index of P&E expenditures. The average age of P&E investment (variable 27, which is the inverse of the average depreciation rate) was derived by finding the average difference between the gross and net fixed assets per dollar of depreciation. Next R&D investment (variable 28) is the sum of intramural expenditures divided by the price index. Output (variable 29) is total sales divided by the producer price index.[3] With an assumed depreciation rate of 10 per

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2 Intramural R&D expenditures of a firm are those relating to the payment of scientist and engineer employees and the purchase of equipment, structures, and land (devoted to R&D investment) by the firm itself.

3 We could have obtained extramural R&D expenditures and generated an additional R&D capital stock. There would be one stock based on intramural and one stock based on extramural expenditures. The two R&D capital stocks, however, would have used up more degrees of freedom than are available for the estimation of the model. It is not, in general, appropriate to aggregate intramural and extramural expenditures. In any event, extramural expenditures are very small.

TABLE 4.4
Derived variables

Variable	Formula
24	$= \left[\sum_{t=75}^{80} \text{Var23}(t)/6\right] \Big/ \left[1 + \sum_{t=75}^{80} \text{Var 19}(t)/6\right]^{5}$
25(t)	$= \text{Var6}(t) - \text{Var6}(t-1) + \text{Var8}(t)$
26(t)	$= \text{Var23}(t)/\text{Var22}(t)$
27	$= \sum_{t=75}^{80} [\text{Var7}(t) - \text{Var6}(t)]/[\text{Var8}(t) \cdot 6]$
28(t)	$= [\text{Var10}(t) + \text{Var11}(t) + \text{Var12}(t) + \text{Var13}(t) +$
$\text{Var14}(t)]$	$\div \text{Var21}(t)$
29(t)	$= [\text{Var1}(t) + \text{Var2}(t)]/\text{Var18}(t)$
30	$= \sum_{t=76}^{80} [(\text{Var29}(t) - \text{Var29}(t-1))/\text{Var29}(t-1)]5$
31(1975)	$= \text{Var28}(1975)/(0.1 + \text{Var30})$
31(t)	$= \text{Var28}(t) + 0.9\text{Var31}(t-1), \quad t = 1976\text{–}1980$
32(1975)	$= \text{Var26}(t)/[(\text{Var27})^{-1} + \text{Var 30}]$
32(t)	$= \text{Var26}(t) + [1 - (\text{Var27})^{-1}]\text{Var 32}(t-1),$ $t = 1976\text{–}1980$
33(t)	$= [\text{Var3}(t) + \text{Var4}(t)]/\text{Var17}(t)$
34(t)	$= 0.5 \left[\text{Var28}(t) \cdot \text{Var21}(t) - \sum_{s=t-1}^{t-3} \text{Var28}(s) \cdot \text{Var21}(s))/3\right],$ $t = 1978\text{–}1980$
35(t)*	$= \text{Var22}(t)[\text{Var19}(t) + (\text{Var27}(t))^{-1}]$ $\times [1 - \text{Var5}(t)/\text{Var25}(t))$ $- (\text{Var24}(t) \cdot \text{Var23}(t))(1 - \text{Var5}(t)/\text{Var25}(t))]$
36(t)*	$= \text{Var21}(t)[\text{Var19}(t) + 0.1]$ $\times [1 - \text{Var23}(t))(1 - (\text{Var16}(t)/\text{Var28}(t) \cdot \text{Var21}(t))$ $- (\text{Var34}(t)/\text{Var28}(t) \cdot \text{Var21}(t))]$

*The formulas for the rental rates on P&E and R&D are the outcome of the dynamic optimizing model presented in Chapter 5.

cent, by initializing R&D capital (by dividing R&D investment by the sum of the depreciation rate and the average growth rate of output (variable 30)), we obtained the R&D capital stock (variable 31) through the declining balance formula.[4] The declining balance formula was also used for the P&E capital stock (variable 32), initializing it by using the inverse of the average age of P&E as the average depreciation rate and the average growth rate of output. The labour input (variable 33) was derived by dividing the labour expenses by the wage index. The R&D tax allowance (which is applicable from 1978 to 1980) is 50 per cent of the excess of current R&D expenditures over the average of the last three years of nominal R&D expenditures.
The formulas for the rental rates on R&D and P&E capital (variables 35 and 36) will be explained in Chapter 5 on the development of the model.

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4 R&D capital stock was also developed with depreciation rates of 8 per cent and 12 per cent. There was very little difference in the empirical results of the model. Pakes and Schankerman (1984) estimated the depreciation rate for R&D capital based on data from four European countries (France, the United Kingdom, the Netherlands, and Switzerland). They found that the rate is greater than that for physical capital.

5

The theoretical model and estimation[1]

Investing in R&D leads to accumulation of the stock of knowledge, which in turn generates output and revenues. Past decisions on the rate and timing of R&D investment influence the present ability of a firm to satisfy its customers and contend with its rivals. This accumulation implies that the determinants of R&D investment, and its interaction with corporate decisions on labour requirements and on physical capital investment, must be the outcome of a dynamic process.

A potentially significant determinant of R&D investment is government policy. The government has directly affected private-sector R&D investment through a number of instruments: contracts, grants, and tax expenditures (see McFetridge 1977). The focus of this study is the investigation of the influence of tax policy, directed towards both R&D and physical capital investment, on the structure of production and R&D expenditures.

We develop a model of corporate production. Output is produced by the means of physical and R&D capital services and labour services. In addition, the accumulation of both types of capital through their respective rates of investment is subject to adjustment costs. These costs are measured by the forgone output as the factors of production are diverted to install additions to physical capital and create additions to R&D capital. Thus there are two types of costs associated with the capital inputs: costs of use and costs of adjustment. The latter imply that the firm cannot adopt instantaneously any level of physical and R&D capital. The

1 This chapter provides details in regard to the general theoretical model, specification of functional forms, and estimation. It may be omitted by readers who are not interested in these technical details.

capital inputs are adjusted over time to the desired level. This adjustment process distinguishes the capital inputs from the labour factor of production. We refer to the latter as a variable factor and the capital inputs as quasi-fixed factors.

The firm under consideration is able to finance physical and R&D investment through debt and share issues and internal funds. In this model we integrate corporate financial and production decisions. The integration is accomplished in part by assuming that the firm operates in the interest of its shareholders and makes its production decisions accordingly.

The tax regime consists of four rates: the corporate income rate, physical and R&D investment credit rates, and the incremental R&D investment allowance rate. We include the following features: labour and interest payments are deductible from taxable income, there is accelerated depreciation on physical capital, R&D expenditures are immediately expensed, the physical investment tax credit reduces the depreciation base, the R&D investment tax credit reduces the amount that can be immediately written off of taxable income, and the incremental allowance on current R&D expenditures is based on the excess over the average of the preceding three years.

In this chapter we begin with a description of the theoretical model. Production and financial decisions are integrated in a framework which admits a complex set of tax rates and incentives. In the first section, we also discuss how the dynamic dual of the model can be represented. In the next section we describe the specification of the model in order to be able to carry out the estimation in the following section. Lastly, we present and discuss the empirical results of the estimation based on the dynamic duality representation.

THEORETICAL DEVELOPMENT

Consider a firm whose production process can be represented by

$$(5.1) \quad y(t) = F[L(t), K_p(t), K_r(t), I_p(t), I_r(t)],$$

where $y(t)$ is output, F is the twice continuously differentiable production function, $L(t)$ is labour services, $K_p(t)$ is physical capital services, $K_r(t)$ is knowledge capital services, $I_p(t)$ is physical capital investment, and $I_r(t)$ is

knowledge capital investment. The variable t represents the time period and for ease of notation we drop it when no ambiguity arises. The marginal products are positive and diminishing for the labour, physical, and R&D capital inputs. The adjustment costs associated with the physical and R&D stocks are internal. Following Treadway (1971, 1974) and Mortenson (1973), we assume that the quasi-fixed factors (i.e., the capital services) are subject to increasing internal costs of adjustment. These costs imply that as additional units of each quasi-fixed input are placed in the production process, the quantity of forgone output rises. Consequently, the average cost of investment increases in response to physical and R&D investment.

The capital stocks accumulate by

$$(5.2) \quad \dot{K}_i = I_i - \delta_i K_i, \quad K_i(0) = K_i^c > 0, \quad i = p,r,$$

where δ_i is the fixed depreciation rate of the i^{th} capital stock.[2] We assume that the firm is a price-taker in all markets and hence the flow of funds can be written as

$$(5.3) \quad py - wL - p_p I_p - p_r I_r + \dot{B} - r_b B - T_c = D - p_s \dot{N}$$

where p is the product price, w is the wage rate, p_i is the price of the i^{th} capital stock (i = p,r), B is the value of corporate debt, r_b is the interest rate on corporate debt, D represents dividends, p_s is the share price, N is the number of shares, and T_c are corporate taxes. We assume static expectations on the prices and the interest rate. Defining the left side of (5.3) as Γ, which is the net flow of funds to shareholders, we can rewrite (5.3) in terms of the value of shares,

$$(5.4) \quad \dot{S} + \Gamma - \rho S = 0,$$

where $S = p_s N$ and $\rho = (D/p_s N) + \dot{p}_s/p_s$ is the cost of equity capital. Assuming that the payout ratio is fixed, and since there are static expectations on the share price, then static expectations prevail on the cost of equity capital.

The solution to equation (5.4) yields the present value of the firm's equity

2 A dot over a variable denotes differentiation with respect to time.

$$\text{(5.5)} \quad S(0) = \int_0^\infty e^{-\rho t}\Gamma(t)dt.$$

We assume that the firm operates in the interest of the shareholders, and therefore the objective is to maximize S(0). The firm fulfils this goal by selecting labour requirements, investment in physical and knowledge capital, and debt issues in the base period (t = 0) conditional on the current values of the exogenous variables. As the base period changes, and new values of the exogenous variables are observed, the firm revises its previous plans. Hence only in the base periods are the plans actually carried out.

In order to carry out the maximization of the present value of equity, it is necessary to characterize more fully the tax environment confronting the firm. In calculating its taxable income, the firm is permitted depreciation deductions on one unit of the i^{th} capital stock of age t (at the original price) equal to $D_i(t)$, i = p,r for physical and R&D capital. It is also true that the unit of the stock must be completely depreciated as

$$\int_0^\infty D_i(t)dt = 1.$$

The depreciation deduction at time t on all units of the i^{th} capital stock is

$$\int_0^\infty p_i(t-\tau)I_i(t-\tau)(1-v_i(t-\tau))D_i(\tau)d\tau, \ i = p,r,$$

where $p_i(t)I_i(t)$ is the capital expenditure on i in period t and $D_i(0)$ is the depreciation deductions on a unit of capital installed in period t. The term $v_i(t)$ is the investment tax credit on the i^{th} stock in period t, and it reduces the base on which the depreciation deductions are calculated. Therefore the tax reduction from depreciation in period t is the corporate tax rate (defined as $u_c(t)$) multiplied by the depreciation deductions.

There is also an incremental investment tax allowance of

$$\gamma_i(t)\int_0^\infty \mu_i(\tau)p_i(t-\tau)I_i(t-\tau)d\tau, \ i = p,r,$$

where $\mu_i(0) = 1$, $\mu_i(\tau) < 0$ for $\tau > 0$, and

$$\gamma_i(t) = \begin{cases} a_i(t) > 0 & \text{if } \int_0^\infty \mu_i(\tau)p_i(t-\tau)I_i(t-\tau)d\tau > 0, \\ 0 & \text{otherwise,} \end{cases}$$

where $a_i(t)$ is the allowance rate in period t and $\mu_i(\tau)$ is the weight applied to investment expenditures incurred in some past time period τ. Hence if current investment expenditures exceed an average of past expenditures then the firm receives a tax allowance on the i^{th} capital stock in period t of $a_i(t)$.[3]

Using the previous results on tax reductions due to depreciation and the incremental tax allowances, the tax liability for the firm in any period of time is

$$(5.6) \quad T_c = u_c(py-wL-r_bB) - \sum_{i=p}^{r}\Big[u_c\int_0^\infty p_i(t-\tau)I_i(t-\tau)(1-v_i(t-\tau))D_i(\tau)d\tau + u_c\gamma_i\int_0^\infty \mu_i(\tau)p_i(t-\tau)I_i(t-\tau)d\tau + v_ip_iI_i\Big].$$

The base of the corporate income tax rate is the net revenues, which are revenues in excess of labour and debt interest payments. In addition, the taxes are reduced by the depreciation deductions, the incremental investment tax allowances, and the investment tax credits.

The present value of the tax liability can be written in two parts, one depending on current decisions and the other the result of past corporate plans. Before we write this expression, we introduce the specific tax policy that there is no incremental investment tax allowance for plant and equipment expenditures (i.e., $\gamma_p(t) = 0$ for all t), and research and development expenditures are deducted from income in the

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3 If we are dealing in discrete time, the expression for $\gamma_i(t)$ to equal $a_i(t)$ is

$$\sum_{\tau=0}^{\infty}\mu_i(\tau)p_i(t-\tau)I_i(t-\tau)d\tau > 0.$$

If $\tau = 0,\ldots,3$ then the expression becomes

$$p_i(t)I_i(t) - \sum_{\tau=1}^{3}p_i(t-\tau)I_i(t-\tau)/3,$$

noting that $\mu_i(0) = 1$, $\mu_i(1) = \mu_i(2) = \mu_i(3) = -1/3$.

period they are incurred (i.e., $D_r(0) = 1$ and $D_r(\tau) = 0$ for all $\tau \neq 0$). Moreover, the investment tax credit is the same for both types of expenditure (i.e., $v_p = v_r = v$). Now the present value of the tax liability is

$$(5.7) \quad \int_0^\infty e^{-\rho t} T_c(t)dt = \int_0^\infty e^{-\rho t}[u_c(py - wL - r_b B - (1-v)p_r I_r) - v\sum_{i=p}^{r} p_i I_i - \int_0^\infty e^{-\rho t}[u_c(t+\tau)p_p(t)I_p(t)(1-v(t))D_p(\tau) + u_c(t+\tau)\gamma_r(t+\tau)\mu_r(\tau)p_r(t)I_r(t)]d\tau - M(t) - N(t)]dt$$

where

$$M(t) = u_c \int_0^\infty p_p(t-\tau)I_p(t-\tau)(1-v(t-\tau))D_p(\tau)d\tau$$

is the tax reduction based on depreciation deductions from past P&E expenditures, and

$$N(t) = u_c\gamma_r(t)\int_0^\infty \mu_r(\tau)p_r(t-\tau)I_r(t-\tau)d\tau$$

is the incremental tax allowance on past R&D expenditures.

Using equation (5.7), the definition of Γ (from equation (5.3)), and assuming static expectations on the tax rates (u_c, v, γ_r), we can write the present value of corporate shares as

$$(5.8) \quad S(0) = \int_0^\infty e^{-\rho t}[(1-u_c)(pF(L,K_p,K_r,I_p,I_r) - wL - r_b B) - p_p I_p(1-v-d_p) - p_r I_r((1-u_c)(1-v) - d_r) + \dot{B} + M + N]dt,$$

where

$$d_p = u_c(1-v)\int_0^\infty e^{-\rho\tau}D_p(\tau)d\tau$$

is the present value of the tax reduction due to depreciation deductions and

$$d_r = u_c\gamma_r\int_0^\infty e^{-\rho\tau}\mu(\tau)d\tau$$

is the present value of tax reductions due to the incremental allowance on R&D expenditures. It is important to realize that the firm's objective has been rearranged so that it is in terms of labour requirements, investment in both physical

and knowledge capital, debt issues, and the legacy of the past (namely K_p, K_r, B, M, and N).

Up to this point we have discussed all the aspects of the model except corporate debt issues. It is now assumed that corporate debt is used to finance the accumulation of the physical and knowledge capital stocks. Indeed, let us suppose that some fraction of debt always goes to finance some proportion of each of the real capital stocks. Thus for $B > 0$

$$(5.9) \quad \psi_p p_p K_p = \theta B, \qquad 0 < \psi_p < 1,\ 0 < \theta < 1,$$

$$(5.10) \quad \psi_r p_r K_r = (1-\theta)B, \quad 0 < \psi_r < 1.$$

Equations (5.9) and (5.10) imply that a fraction of physical capital (ψ_p) and some fraction of knowledge capital (ψ_r) exhaust the uses of debt. However, it is possible for the real capital stocks to be financed through internal funds and new share issues, since both ψ_p and ψ_r are positive but less than unity. Differences in ψ_p and ψ_r reflect the relative costs of financing the two types of capital stock through corporate bonds. The cost difference is reflected in the simplest manner as ψ_p and ψ_r are constants.

Equations (5.9) and (5.10) can be written in terms of the investment in P&E and R&D. Using the assumption of static expections on the prices (p_p, p_r), we have

$$(5.11) \quad \psi_p p_p \dot{K}_p + \psi_r p_r \dot{K}_r = \dot{B}.$$

Substituting (5.9)-(5.11) into (5.8) and integrating by parts yields

$$V(0) = \int_0^\infty e^{-\rho t}[p_y F(L,K_p,K_r,I_p,I_r) - w_\ell L - w_q K_p - w_s K_r]dt,$$

where

$$V(0) = S(0) - \int_0^\infty e^{-\rho t}(M(t) + N(t))dt,$$

$$p_y = p(1-u_c),$$

$$w_\ell = w(1-u_c),$$

$$w_q = p_p[(\rho+\delta_p)(1-v-d_p) + \psi_p(r_b(1-u_c) - \rho)],$$

and

$$w_s = p_r[(\rho+\delta_r)((1-u_c)(1-v)-d_r) + \psi_r(r_b(1-u_c) - \rho)].$$

The prices w_q and w_s are the post-tax rental rates on P&E and R&D capital. The problem confronting the firm is to maximize V(0) by selecting L, I_p, and I_r subject to the equations depicting the accumulation of real capital (i.e., equation set (5.2)) and the initial conditions on these stocks.

Before we proceed, it is instructive to decompose the rental rates on physical and knowledge capital, since the tax policy instruments operate through these variables. Consider the rental rate on P&E (w_q). If the firm is all equity-financed ($\psi_p = 0$), there is no investment tax credit ($v = 0$), and the tax authorities allow only economic depreciation ($d_p = u_c\delta/(\rho+\delta)$), then the post-tax rental rate is equal to $p_p(\rho + \delta_p(1-u_c))$. However, if the firm is all debt-financed ($\psi_p = 1$) then the rental rate is $p_p(r_b+\delta)(1-u_c)$, and if the firm is both debt- and equity-financed ($0 < \psi_p < 1$), the rental rate is $p_p[(1-\psi_p)\rho + \psi_p r_b(1-u_c) + \delta(1-u_c)]$. The term $(1-\psi_p)\rho + \psi_p r_b(1-u_c)$ is defined as the average (financial) cost of physical capital, and it is the traditional weighted average of the (average) costs of debt and equity financing. The expression $\psi_p(r_b(1-u_c) - \rho)$ represents the modification to the rental rate for the partially debt-financed firm relative to the all equity-financing situation. Finally, the existence of both an investment tax credit and accelerated depreciation decreases the rental rate. Similar reasoning can be used to explain the nature of the post-tax rental rate for R&D capital.

In order for shareholders' net flow of funds to be maximized, the firm must intertemporally minimize costs. Inverting the production function to obtain the labour requirements function,

$$L = G(K_p, K_r, I_p, I_r, y),$$

the cost-minimization problem, for any given output, can be written as

$$\min_{(I_r, I_p)} \int_0^\infty e^{-\rho t}[w_\ell G(K_p,K_r,I_p,I_r,y) + w_q K_p + w_s K_r]dt,$$

subject to

$$\dot{K}_i = I_i - \delta_i K, \quad K_i(0) = K_i^c > 0, \quad i = p,r.$$

There are two ways in which we can represent the optimality conditions for the cost-minimizing problem: the primal and the dual. We shall concentrate on the dual to this problem, because of the flexibility this approach provides for the estimation of the model. Define $J(K_p,K_r,w_\ell,w_q,w_s,y)$ to be the minimized present value of costs, and therefore (see Dreyfus 1965, Arrow and Kurz 1970, and Epstein 1981)

$$\rho J = w_\ell G(K_p,K_r,I_p^o,I_r^o,y) + w_q K_p + w_s K_r + J_p(I_p^o - \delta K_p) + J_r(I_r^o - \delta_r K_r), \tag{5.12}$$

where $\partial J/\partial K_i = J_i$, $i = p,r$, and the superscript o denotes the cost-minimizing quantitites. The conditions determining the optimal quantities for I_p and I_r are found by differentiating (5.12) with respect to w_q and w_s. Thus

$$\rho J_q = K_p + J_{pq}(I_p^o - \delta_p K_p) + J_{rq}(I_r^o - \delta_r K_r), \tag{5.13}$$

$$\rho J_s = K_r + J_{ps}(I_p^o - \delta_p K_p) + J_{rs}(I_r^o - \delta_r K_r), \tag{5.14}$$

where $\delta J/\delta w_j = J_j$, $j = q$, s. Solving equations (5.12)-(5.14) yields

$$\begin{aligned} \dot{K}^o &= J_{k\omega}^{-1}(\rho J_\omega - K), \\ L^o &= \rho(J - \omega^T J_\omega) - [J_k^T - \omega^T J_{k\omega}]\dot{K}^o, \end{aligned} \tag{5.15}$$

where

$$J_{k\omega} = \begin{bmatrix} J_{pq} & J_{rq} \\ J_{ps} & J_{rs} \end{bmatrix}, \quad J_\omega = \begin{bmatrix} J_q \\ J_s \end{bmatrix}, \quad J_k = \begin{bmatrix} J_p \\ J_r \end{bmatrix},$$

$$K = \begin{bmatrix} K_p \\ K_r \end{bmatrix}, \quad \omega = \begin{bmatrix} w_q \\ w_s \end{bmatrix}, \quad \dot{K}^o = \begin{bmatrix} I_p^o - \delta_p K_p \\ I_r^o - \delta_r K_r \end{bmatrix},$$

and w_ℓ is normalized to unity so that the rental rates are now defined relative to the wage rate. Equation set (5.15) is the model that is to be estimated. Notice that the model is a recursive system. The investment equations ($\dot{K}^o$) are a

system of two equations in two unknowns. The solution to the investment equations is then substituted into the labour-requirements equation (L^o).

MODEL SPECIFICATION

In order to estimate equation set (5.15), a functional form for the minimized present value of costs must be specified and an error structure imposed. We hypothesize the following functional form (see Epstein and Denny 1983):

$$(5.16)\quad J(K_p, K_r, w_q, w_s, y) = [\omega^T 1]\begin{bmatrix} B_{\omega\omega} & b_\omega \\ b_\omega^T & b_0 \end{bmatrix}[\omega_1^T]y/2$$

$$+ [\omega^T A_{\omega k}^{-1} + a_k^T]K + [\omega^T A_{\omega k}^{-1} h_\omega + h_0]/\rho.$$

The form given by the right side of equation (5.16) is linear-quadratic in factor prices and linear in output and the capital stocks. Moreover, it is consistent with the aggregation across technologies (e.g., across plants, establishments, or corporations). The parameters in $B_{\omega\omega}$ form a 2 by 2 symmetric matrix, which must be negative definite ($b_{ii} < 0$, $i = 1,2$, $b_{11}b_{22} - b_{12}^2 > 0$); b_ω, a_k, and h_ω are 2-dimensional column vectors; $A_{\omega k}^{-1}$ is the inverse of a 2 by 2 matrix of parameters, such that $\rho I_2 - A_{\omega k}$ must be stable (sufficient conditions for this are $0 < a_{ii} - \rho < 1$, $i = 1,2$, and $(a_{11} - \rho)(a_{22} - \rho) - a_{12}a_{21} > 0$; I_2 is the 2 by 2 identity matrix); b_0 and h_0 are scalar parameters; and the superscript T represents the operation of vector transposition.[4]

The corresponding set of investment and labour demand functions implied by (5.16) can be derived by noting that

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4 The matrices are $B_{\omega\omega} = \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix}$, $A_{\omega k} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}$.

The vectors are $b_\omega = \begin{bmatrix} b_1 \\ b_2 \end{bmatrix}$, $a_k = \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$, $h_\omega = \begin{bmatrix} h_1 \\ h_2 \end{bmatrix}$.

$$\rho J_{\omega} = \rho(B_{\omega\omega}\omega + b_{\omega})y + \rho A_{\omega k}^{-1}K + A_{\omega k}^{-1}h_{\omega},$$

$$J_{k\omega} = A_{\omega k}^{-1}.$$

Hence using (5.15) we get

$$\begin{aligned} \dot{K}^{o} &= \rho A_{\omega k}(B_{\omega\omega}\omega + b_{\omega})y + h_{\omega} + (\rho I_2 - A_{\omega k})K, \\ L^{o} &= \rho(b_0 - \omega^T B_{\omega\omega}\omega)y/2 + h_0 + \rho a_k^T K - a_k^T \dot{K}^{o}. \end{aligned} \tag{5.17}$$

These two equations are the equations to be estimated. They are our preferred specification. Notice that the investment demand functions are linear in the rental rates and the capital stocks, while the labour demand equation is linear in the capital stocks and the rates of net investment. In addition, the net investment equations are flexible accelerators since we can write

$$\dot{K}^{o} = M(K - K^{s}),$$

where $K^{s} = -(\rho I_2 - A_{\omega k}^{-1})(\rho A_{\omega k}(B_{\omega\omega}\omega + b_{\omega})y + h_{\omega})$ represents the long-run (or stationary state) levels of the capital stocks and $M = \rho I_2 - A_{\omega k}$ is the adjustment matrix. An advantage of the dual approach to the dynamic problem is that the adjustment matrix is expressed in terms of the parameters of the value function, J. Thus the specification of the technology can be quite flexible in terms of allowing interaction between the capital stocks and the rates of investment. Solution of the primal problem usually necessitates an assumption that the adjustment matrix is diagonal. A diagonal adjustment matrix implies that the elasticity of substitution between the capital stocks is zero, and the marginal adjustment cost of a particular form of capital depends only on that type of capital. These are strong assumptions which have not been imposed in the present context.

The system (namely equation set (5.17)) that is to be estimated is non-linear in the parameters, with restrictions on parameters within and across equations. As we have mentioned, the system is linear in the quantities and block-recursive in the sense that the two net investment equations are simultaneous. The solutions to these two equations then feed into the labour demand equation. By taking a discrete

approximation to (5.17), where $\dot{K}(t) \approx K(t) - K(t-1)$ and $K \approx K(t-1)$, and by appending error terms $(u(t))$ to each of the equations, which are assumed to be jointly normally distributed with zero mean $(E(u) = 0)$ and with positive definite symmetric covariance matrix $(E(uu^T) = \Omega \otimes I_T = \Phi$, where Ω is a 3 by 3 matrix), we can use the non-linear maximum likelihood estimator.

The estimated equations can be written out as follows:

$$(5.18)\quad \frac{L^o(t)}{y} = b_0\frac{\rho}{2} - b_{11}\frac{\rho}{2}(\omega_p+\psi_p\omega_e)^2 - b_{12}\rho(\omega_p+\psi_p\omega_e)(\omega_r+\psi_r\omega_d) - b_{22}\frac{\rho}{2}(\omega_r+\psi_r\omega_d)^2 + \frac{h_0}{y} + a_1(1+\rho)\frac{K_p(t-1)}{y} + a_2(1+\rho)\frac{K_r(t-1)}{y} - a_1\frac{K_p^o(t)}{y} - a_2\frac{K_r^o(t)}{y} + u_\ell(t),$$

$$(5.19)\quad \frac{K_p^o(t)}{y} = (a_{11}b_{11} + a_{12}b_{12})\rho(\omega_p + \psi_p\omega_e) + (a_{11}b_{12} + a_{12}b_{22})\rho(\omega_r + \psi_r\omega_d) + (a_{11}b_1 + a_{12}b_2)\rho + \frac{h_1}{y} + (1 + \rho - a_{11})\frac{K_p(t-1)}{y} - a_{12}\frac{K_r(t-1)}{y} + u_p(t),$$

$$(5.20)\quad \frac{K_r^o(t)}{y} = (a_{21}b_{11} + a_{22}b_{12})\rho(\omega_p + \psi_p\omega_e) + (a_{21}b_{12} + a_{22}b_{22})\rho(\omega_r+\psi_r\omega_d) + (a_{21}b_1 + a_{22}b_2)\rho + \frac{h_2}{y} - a_{21}\frac{K_p(t-1)}{y} + (1 + \rho - a_{22})\frac{K_r(t-1)}{y} + u_r(t),$$

where $\omega_p = p_p(\rho+\delta_p)(1-v-d_p)/w_\ell$, $\omega_e = p_p(r_b(1-u_c) - \rho)/w_\ell$, $\omega_r = p_r(\rho+\delta_r)((1-u_c)(1-v) - d_r)/w_\ell$, $\omega_d = p_r(r_b(1-u_c) - \rho)/w_\ell$.

MODEL ESTIMATION

The sample consisted of 27 firms, with observations from 1976 to 1980 (after accommodating variable derivations). Pooling the data gave us 135 observations. In addition, we allowed for inter-firm differences by permitting h_0, h_1, and h_2 to vary across firms.[5] Thus from the three equations (5.18), (5.19), and (5.20) there were 95 parameters to estimate.[6]

The estimates are presented in Table 5.1. To obtain these, we used the mean value of $\rho = 0.0873$. The estimation procedure was the following. First we jointly estimated equations (5.19) and (5.20), since they depend on exogenous variables only. The estimator was the non-linear maximum likelihood for seemingly unrelated equations. We imposed the within- and across-equation restrictions on the parameters. The estimation of these two equations involves 65 parameters.[7] Second, using the estimates from the capital input demand equations and the calculated capital inputs, we estimated the remaining 30 parameters (b_0, a_1, a_2, and the twenty-seven h_0's) from the labour demand equation.[8] At each stage the estimation procedure converged with a criterion of 0.001. Although there is no method that guarantees a global maximum for the likelihood function, different starting values yielded essentially identical parameter estimates. The asymptotic t-statistics imply that the coefficients are significant. In Table 5.1 we present the mean values based on the estimates of h_0, h_1, and h_2 for different firms. In

5 Inadequate degrees of freedom did not permit us to estimate the system of equations with more complex inter-firm differences in the parameters.

6 Of the total number of parameters, 81 are related to the firm-specific parameters of h_0, h_1, and h_2.

7 Of the 65 parameters in the two investment equations 54 are related to the firm-specific parameters h_1 and h_2.

8 We had to use the two-step estimation procedure because of software limitations on the combination of the number of observations and parameters h_1 and h_2.

TABLE 5.1
Estimation results

Parameter	Estimate	t-statistic
b_0	4.5017	2.3362
b_{11}	-2.0299	-3.4089
b_{12}	-0.34996	-3.7288
b_{22}	-1.0396	-2.8169
h_0*	5.6906	
a_{11}	0.30015	2,1970
a_{12}	0.04903	3.1116
a_{22}	0.25006	1.6820
a_{21}	0.00890	-1.9371
a_1	-0.60106	-2.5158
a_2	-0.60148	-2.9900
b_1	13.602	2.3350
b_2	5.2018	1.4668
ψ_p	0.47385	1.2339
ψ_r	0.09312	1.5932
h_1*	7.1412	
h_2*	6.8241	

Log likelihood = 269.4303.
*The values of h_0, h_1, h_2 are the mean values of the 27 different estimates for each firm.

addition, from Table 5.1 notice that $b_{ii} < 0$, i = 1,2; also $b_{ii} < 0$, i = 1,2, and $b_{11}b_{22} - b_{12}^2 > 0$. In addition, $0 < a_{ii} < 1 + \rho$, i = 1,2, and $(a_{11}-\rho)(a_{22}-\rho) - a_{12}a_{21} > 0$.

The major analysis of the regression results will be taken up in succeeding chapters on factor price, tax, output, and financing effects. At this point we want to discuss the nature of the dynamics in the model. From the theoretical

development, we know that the investment equations are in the flexible accelerator model class. Indeed, as we have established, the adjustment matrix is $M = \rho I_2 - A_{\omega k}$. The elements of the 2 by 2 matrix $A_{\omega k}$ are a_{ij}, $i,j = 1,2$. These four coefficients (a_{11}, a_{12}, a_{22}, a_{21}) illustrate the speed of adjustment of the capital inputs to their respective long-run levels. First, $a_{11}-\rho$ illustrates the proportion of the adjustment for physical capital that takes place in a single year, given the stock of knowledge capital. Second, the same meaning is ascribed to $a_{22}-\rho$ for R&D capital, given the stock of physical capital. In the present model there are also 'cross-effects' associated with the adjustment process. The coefficient $-a_{12}$ illustrates the adjustment in physical capital associated with changes in R&D capital, and $-a_{21}$ illustrates the converse situation.

From Table 5.1, we can observe the coefficients characterizing the speeds of adjustment. First, for physical capital 0.213($a_{11}-\rho$) or 21.3 per cent of the adjustment takes place in a single year, given the stock of R&D capital. This means that it takes 4.7 years for physical capital to attain its long-run level.

We find that R&D capital takes 6.1 years to adjust to its long-run level, given the stock of physical capital. Notice that 0.164($a_{22}-\rho$) or 16.4 per cent of the adjustment of R&D capital occurs in a single year.

Turning to the cross-effects, we find that a deficient stock of R&D capital (relative to its long-run level) causes the physical capital stock to decrease by 0.049($-a_{12}$) or 4.9 per cent in one year. A deficient stock of physical capital causes the stock of R&D capital to decline by 0.009($-a_{21}$) or 0.9 per cent in one year.

A number of results emerge from the adjustment process. First, with respect to the own effects (i.e. $a_{11}-\rho$ and $a_{22}-\rho$), physical capital adjusts faster than does R&D capital. Second, the cross-effects illustrate that there is a form of complementarity between the capital stocks along the adjustment path (as $-a_{12}$ and $-a_{21}$ are positive) to the long-run equilibrium. Third, changes in R&D capital exert a

stronger influence on physical capital accumulation than do changes in accumulation on R&D capital (that is $|a_{12}| > |a_{21}|$).

Fourth, the own effects are larger than the cross-effects. Indeed, the cross-effects are quite small, though, nevertheless, statistically significant. Fifth, the combined effect on physical capital implies that 26.2 per cent of the adjustment occurs in a single year or the net process takes a little more than 3.8 years. The combined effect on R&D capital results in 17.3 per cent of the adjustment occurring in one year and the process taking about 5.8 years.

6

Price and output determinants of factor demands

The demand for factors of production, including R&D capital, responds to changes in the prices firms must pay for these inputs. Price changes can be generated by market forces or government policy. Indeed, regarding the latter, changes in tax rates, credits, and allowances affect the unit cost or price firms pay for their factors of production. For example, suppose a firm pays $1 for the use of a machine in production. If the government permits a tax credit of $0.10 for each new machine then the after-tax price of the machine is reduced to $0.90.[1] Thus, in order to determine the effects of tax policy on the demand for factors of production, it is imperative to estimate the response of input demands to price changes.

Generally, changes in factor prices elicit two types of effects on input demands. Consider, for example, an increase in the wage rate paid to labour. If labour becomes relatively more expensive then the firm will substitute at least one of the other factors of production (for example, physical capital) for labour in the production process. Thus the relative quantities of the inputs used to produce the existing level of output are affected by the change in the wage rate. In other words, factor proportions are altered.

The increase in the wage rate, besides changing factor proportions at the existing level of output, raises the production costs to the firm, with the result that the supply of output decreases. Consequently, any input price increase changes input demands such that both factor proportions and output supply are affected. These are distinct effects, which occur for a change in any one factor price.

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1 In Chapter 3 we discussed how tax policy affects the unit cost of R&D expenditures.

To date we do not have any quantitative evidence on these substitution and output effects relating to the demand for R&D capital. In particular, we do not know how the demand for R&D capital (and thereby also R&D expenditures) is affected by changes in the wage rate, the factor price of physical capital (which is plant and equipment), and the factor price of R&D capital itself. The purpose of this chapter is to measure the response of R&D capital demand (and in turn R&D expenditures) to changes in each factor price. We undertake this task for the major firms undertaking R&D expenditures in the Canadian economy.[2] Moreover, because we are interested in investigating the structure of production of these major firms, we also determine the effects of changes in each factor price on the demands for every input.

SUBSTITUTION EFFECTS

In this section we want to investigate the effects of factor-price changes on input demands at the existing level of output. In other words, we are addressing the issue that concerns changes in factor quantities used to produce the given supply of output in response to changes in each of the factor prices. These effects are referred to as substitution effects or compensated factor-price elasticities.

There are two types of substitution effects: those that arise in the short run and those in the long run. The long-run type is differentiated from the short-run by defining the former as the situation when all investment in physical and R&D capital is just sufficient to replace that part of the capital stocks that has depreciated. Thus, there is no further growth in either of the capital stocks in the long run.

Short-run

The short-run compensated factor-price elasticities defined at the existing level of output are derived from equations (5.18)-(5.20). This system of equations is differentiated with respect to each of the factor prices: w_q, the factor price or rental rate on physical capital; w_s, the factor

2 The responses relate to the 27 firms described in the data bank in Chapter 4.

price or rental rate on R&D capital; and w_ℓ, the factor price of labour or the wage rate. The formulas for these short-run compensated factor price elasticities are found in Table 6.1 and the effects themselves are given in Table 6.2.

From Table 6.2 we can observe that an increase in a factor price decreases its respective factor demand (the diagonal terms are negative). Moreover, the effects associated with each of the capital inputs are quite similar. A 1 per cent increase in a rental rate descreases the demand for that capital input by 0.12 per cent. Labour demand is the most price-responsive with an effect that is almost one for one: a 1 per cent increase in the wage rate decreases labour demand by 0.94 per cent at the given level of output.

The off-diagonal elements in Table 6.2 show how factor demands respond to changes in factor prices other than their own. Indeed, the off-diagonal terms may be called 'cross-effects' while the diagonal terms are referred to as 'own effects.' From Table 6.2 we see that a 1 per cent increase in the rental rate on physical capital decreases the demand for R&D capital by only 0.05 per cent and increases the demand for labour by almost 0.7 per cent. We see that this type of movement is preserved if we consider a 1 per cent increase in the rental rate on R&D capital. We find that physical capital then decreases by about 0.01 per cent and labour requirements increase by 0.25 per cent. Thus the capital inputs are complementary factors because an increase in the rental rate on R&D capital causes a decrease not only in the demand for R&D capital but also in the demand for physical capital. The same result occurs for an increase in the rental rate on physical capital. In addition, both capital inputs are substitutes for labour. An increase in the wage rate causes the firms to increase their demand for physical and R&D capital by 0.13 per cent and 0.18 per cent respectively, while labour demand decreases. Hence decreases in both rental rates and an increase in the wage rate cause these firms to become relatively more capital-intensive in their production of the existing level of output. The increased capital intensity refers to both physical and R&D capital.

R&D capital does, in fact, respond to changes in its own rental rate and to changes in the prices of the other inputs used by the firms in their production processes. Moreover, changes in the rental rate on R&D capital cause the firms to alter not only their demand for R&D capital but also their demands for physical capital and labour.

TABLE 6.1

Formulas for the short-run compensated factor-price elasticities

Factor price	Factor demand		
	K_p^s (physical capital)	K_r^s (knowledge capital)	L^s (labour)
w_q (physical capital)	$e_{pq}^s = \frac{\omega_q \rho y}{K_p^s}(a_{11}b_{11}+a_{12}b_{12})$	$e_{rq}^s = \frac{\omega_q \rho y}{K_r^s}(a_{12}b_{11}+a_{22}b_{12})$	$e_{\ell q}^s = -\frac{\omega_q \rho y}{L^s}(b_{11}\omega_q+b_{12}\omega_s)$ $-a_1\frac{K_p^s}{L^s}e_{pq}^s - a_2\frac{K_r^s}{L^s}e_{rq}^s$
w_s (knowledge capital)	$e_{ps}^s = \frac{\omega_s \rho y}{K_p^s}(a_{11}b_{12}+a_{21}b_{22})$	$e_{rs}^s = \frac{\omega_s \rho y}{K_r^s}(a_{21}b_{12}+a_{22}b_{22})$	$e_{\ell s}^s = -\frac{\omega_s \rho y}{L^s}(b_{12}\omega_q+b_{22}\omega_s)$ $-a_1\frac{K_p^s}{L^s}e_{ps}^s - a_2\frac{K_r^s}{L^s}e_{rs}^s$
w_ℓ (labour)	$e_{p\ell}^s = -(e_{pq}^s + e_{ps}^s)$	$e_{r\ell}^s = -(e_{rq}^s + e_{rs}^s)$	$e_{\ell\ell}^s = -(e_{\ell q}^s + e_{\ell s}^s)$

TABLE 6.2
Short-run compensated factor-price elasticities
(in per cent)

	Factor demand*		
Factor price	K_p^s (physical capital)	K_r^s (knowledge capital)	L^s (labour)
w_q	-0.1230	-0.0472	0.6911
w_s	-0.0083	-0.1284	0.2492
w_l	0.1313	0.1756	-0.9403

*The elasticities are based on a 1 per cent increase in each factor price.

Long-run

In the long run there is no growth in the physical and R&D capital stocks. Any investment just replaces that part of the stock that has depreciated. The formulas for the long-run compensated price elasticities are given in Table 6.3 and the effects in Table 6.4. A number of results emerge from the latter table. First, an increase in each of the factor prices decreases the corresponding factor demand. In other words along the diagonal of Table 6.4 the values are negative. An increase of 1 per cent in the rental rate of physical capital causes the demand for physical capital to decrease by about 0.30 per cent. For knowledge capital, when its factor price rises by 1 per cent, the demand falls by 0.32 per cent. Finally, labour demand decreases by 1.60 per cent when the wage rate rises by 1 per cent. Clearly, as in the short run, labour exhibits the largest response, while the magnitudes for physical and knowledge capital are roughly the same.

Turning to the off-diagonal elements in Table 6.4, we see that an increase in the rental rate for physical capital decreases the demand for knowledge capital and increases labour requirements. Similarly, as the rental rate on knowledge capital rises, the demand for physical capital falls and labour requirements increase. Therefore, in the long run (as well as the short run) knowledge and physical capital are complementary factors, while each of the capital inputs is a substitute for labour.

TABLE 6.3

Formulas for the long-run compensated factor-price elasticities

Factor price	Factor demand*: K_p^L (physical capital)	K_r^L (knowledge capital)	L^L (labour)
w_q (physical capital)	$e_{pq}^L = \frac{\omega_q \rho y}{K_p^L H}[(a_{11}b_{11}+a_{12}b_{12}) \times (a_{22}-\rho) - (a_{21}b_{11}+a_{22}b_{12})a_{12}]$	$e_{rq}^L = \frac{\omega_q \rho y}{K_r^L H}[(a_{21}b_{11}+a_{22}b_{12}) \times (a_{11}-\rho) - (a_{11}b_{11}+a_{12}b_{12})a_{21}]$	$e_{\ell q}^L = -\frac{\omega_q \rho y}{L^L}(b_{11}\omega_q+b_{12}\omega_s) + a_1\rho\frac{K_p^L}{L^L}e_{pq}^L + a_2\rho\frac{K_r^L}{L^L}e_{rq}^L$
w_s (knowledge capital)	$e_{ps}^L = \frac{\omega_s \rho y}{K_p^L H}[(a_{11}b_{12}+a_{12}b_{22}) \times (a_{22}-\rho) - (a_{21}b_{12}+a_{22}b_{22})a_{12}]$	$e_{rs}^L = \frac{\omega_s \rho y}{K_r^L H}[(a_{21}b_{12}+a_{22}b_{22}) \times (a_{11}-\rho) - (a_{11}b_{12}+a_{12}b_{22})a_{21}]$	$e_{\ell s}^L = -\frac{\omega_s \rho y}{L^L}(b_{12}\omega_q+b_{22}\omega_s) + a_1\rho\frac{K_p^L}{L^L}e_{ps}^L + a_2\rho\frac{K_r^L}{L^L}e_{rs}^L$
w_ℓ (labour)	$e_{p\ell}^L = -(e_{pq}^L + e_{ps}^L)$	$e_{r\ell}^L = -(e_{rq}^L + e_{rs}^L)$	$e_{\ell\ell}^L = -(e_{\ell q}^L + e_{\ell s}^L)$

*The term H in the formulas is defined as $(a_{11}-\rho)(a_{22}-\rho) - a_{12}a_{21}$.

TABLE 6.4
Long-run compensated factor-price elasticities (in per cent)

Factor price	Factor demand* K_p^L	K_r^L	L^L
w_q	-0.3038	-0.1600	1.1702
w_s	-0.0480	-0.3240	0.4265
w_ℓ	-0.3518	0.4840	-1.5967

*The elasticities are based on a 1 per cent increase in each factor price.

OUTPUT EFFECTS

There are two effects on factor demands resulting from a change in a factor price: the substitution and the output effect. The output effect arises because a change in a factor price affects the cost of production. The change in costs generates a change in the supply of output, which in turn causes the demands for the factors of production to be altered. Thus the output effect is the product of two sub-effects, one relating to the relationship between production costs and output and the other pertaining to the relationship between output and the factor demands. The latter is called the output elasticity of factor demand.

In order to determine the output effects of factor-price changes, we must find first the effect of a change in any factor price on production costs and thereby on output, and second the effect of output on the factor demands. Regarding the first step, a change in any input price affects production costs in such a fashion that the marginal cost of producing output changes. For example, if the input price increases, which then causes the marginal cost of production to rise, output will decrease. However, the extent of the decrease depends on the nature of a firm's product demand.

The reason product demand enters the picture is that as the marginal cost increases, firms attempt to recoup the higher costs by raising product prices. The extent that any firm is able to ameliorate the higher marginal costs by raising its price depends on the price responsiveness of product demand. If product demand is quite price-responsive then the firm is unable to raise its price to any great extent because customers will shift to the products of rival

firms. If product demand is not very price-responsive then firms will be able to recover the higher marginal costs through price increases. Thus, as marginal costs rise firms attempt to adjust to the situation by decreasing output and increasing product price. On net, the change in output depends on the magnitude by which marginal costs increase and the degree to which product demand is price-responsive. The formulas for the effect on output of an increase in the marginal cost generated by an increase in one of the factor prices are presented in Table 6.5.[3]

The second aspect in determining the output effects of factor-price changes is measuring the response of a factor demand to a change in output, or the output elasticity of factor demand. The formulas are given in Table 6.6, and the elasticities are presented in Table 6.7.

We see that in the short run an increase in output generates a relatively greater increase in labour requirements. This is due to the fact that output expansion must be forthcoming from the intensive use of labour in the short run as there are adjustment costs to be absorbed by the firm in order for it to change the levels of the capital inputs to produce the increase in output. Thus because the capital inputs are quasi-fixed factors the increase in output is produced relatively more by labour. The firms overshoot their labour requirements in the short run by increasing labour demand by a greater percentage than the percentage increase in output. In the long run, as adjustment costs are absorbed and the capital inputs become more flexible, firms are able to supply increases in output by almost equiproportional increases in output.

Since the output effects of factor-price changes are the combination of two sub-effects - first, the impact of a factor-price change on output and, second, the impact of output on the factor demands - we must multiply the terms in Tables 6.5 and 6.6 to obtain the output effects. That is, for an increase in the rental rate of physical capital the long-run output effects on physical and knowledge capital and labour requirements are found by multiplying the first expression in Table 6.5 by each of the terms in the first row of Table 6.6. In the short run, we multiply the first term (calculated at the short-run factor demand) in Table 6.5 by each of the terms in the second row of Table 6.6.

3 These formulas are derived by assuming that the product demand function has a constant price elasticity.

TABLE 6.5

Formulas for the output responses of factor-price changes

Factor price	Long-run*	Short-run**
w_q (physical capital)	$e^L_{yq} = e^L_{py} s^L_p \varepsilon$	$e^s_{yq} = \varepsilon s^s_p [a_{22} e^s_{py} - a_{21} e^s_{ry} (K^s_r / K^s_p)] / Ae^s_{cy}$
w_s. (knowledge capital)	$e^L_{ys} = e^L_{ry} s^L_r \varepsilon$	$e^s_{ys} = \varepsilon s^s_r [-a_{12} e^s_{py} (K^s_p / K^s_r) + a_{11} e^s_{ry}] / Ae^s_{cy}$
w_ℓ (labour)	$e^L_{y\ell} = e^L_{\ell y} s^L_\ell \varepsilon$	$e^s_{y\ell} = \varepsilon e^s_{cy} - e^s_{yq} - e^s_{ys}$

*The terms are defined as follows: e^L_{iy} is the long-run output elasticity of the i^{th} input, s^L_i is the long-run cost share of the i^{th} input, and ε is the price elasticity of product demand.

**The superscript s stands for short-run; and the terms are otherwise defined as in the long-run with e^s_{cy} the short-run output elasticity of costs. $A = a_{11}a_{22} - a_{12}a_{21}$.

TABLE 6.6

Formulas for the long- and short-run output elasticities of factor demands

Factor demand	Long-run*	Short-run
K_p	$e^L_{py} = 1 - h_1(a_{22}-\rho)/K^L_pH + h_2a_{12}/K^L_pH$	$e^s_{py} = 1 - h_1/K^s_p - (1+\rho-a_{11})(K_p(t-1)/K^s_p)$
		$+ a_{12}K_r(t-1)/K^s_p$
K_r	$e^L_{ry} = 1 - h_2(a_{11}-\rho)/K^L_rH + h_1a_{21}/K^L_rH$	$e^s_{ry} = 1 - h_2/K^s_r + a_{21}(K_p(t-1)/K^s_r)$
		$- (1+\rho-a_{22})(K_r(t-1)/K^s_r)$
L	$e^L_{\ell y} = 1 - h_0/L^L + a_1\rho e^L_{py}K^L_p/L^L$	$e^s_{\ell y} = 1 - h_0/L^s - a_1(1+\rho)(K_p(t-1)/L^s)$
	$+ a_2\rho e^L_{ry}K^L_r/L^L$	$- a_2(1+\rho)(K_r(t-1)/L^s) + a_1K^s_p/L^s$
	$- a_1\rho K^L_p/L^L - a_2\rho K^L_r/L^L$	$+ a_2K^s_r/L^s - a_1e^s_{py}K^s_p/L^s - a_2e^s_{ry}K^s_r/L^s$

*The term H in the formulas is defined as $(a_{11}-\rho)(a_{22}-\rho)-a_{12}a_{21}$.

TABLE 6.7
Long-and short-run output elasticities of factor demands (in per cent)

	Factor demand*		
	K_p	K_r	L
Long-run	0.9999	0.9998	0.9012
Short-run	0.1590	0.2216	1.2321

*The elasticities are based on a 1 per cent increase in output.

The procedure is the same when the rental rate on knowledge capital and the wage rate increase. In these cases we use the second and third rows respectively in Table 6.5.

In order to utilize the formulas in Table 6.5 we must have measures of the price responsiveness of product demand for the different firms in the sample. In view of the absence of estimating these magnitudes we compute the output effects for three different values of the degree of price responsiveness: -1.5, -3, and -6. These figures represent the percentage decrease in product demand resulting from a 1 per cent increase in the product price. These magnitudes capture a realistic spectrum of the price sensitivity or elasticity of product demand.[4]

The output effects of factor-price changes are given in Tables 6.8 to 6.10. In computing the magnitudes found in these tables we used the after-tax cost share of each of the inputs. At the mean in the long run, the labour share is 0.57, the share of physical capital is 0.36, and the R&D capital cost share is 0.07. In the short run the shares are respectively 0.48, 0.31, 0.05, with 0.16 of total costs comprising adjustment costs associated with the capital inputs. In each of the tables, for any price elasticity of product demand, the long-run figures are governed by the cost shares and the output elasticities, while the short-run figures are determined by these elements and the marginal adjustment costs associated with the capital inputs.

First, from Table 6.8 we observe that the short-run output effects for the capital inputs are less (in absolute value) than the long-run effects. This result occurs because

4 The interested reader can compute the output effects and the ensuing factor-price effects for other values of product-price elasticities by using the same procedure as outlined in the text.

TABLE 6.8
Output effects on factor demands of a change in the rental rate on physical capital
(in per cent)

Factor demand*		Price elasticity of product demand -1.5	-3	-6
K_p	Long-run	-0.540	-1.080	-2.160
	Short-run	-0.065	-0.129	-0.257
K_r	Long-run	-0.540	-1.080	-2.160
	Short-run	-0.089	-0.179	-0.357
L	Long-run	-0.487	-0.974	-1.947
	Short-run	-0.497	-0.994	-1.987

*The effects are based on a 1 per cent increase in the rental rate on physical capital.

TABLE 6.9
Output effects on factor demands of a change in the rental rate on R&D capital
(in per cent)

Factor demand*		Price elasticity of product demand -1.5	-3	-6
K_p	Long-run	-0.105	-0.210	-0.420
	Short-run	-0.025	-0.049	-0.099
K_r	Long-run	-0.105	-0.210	-0.420
	Short-run	-0.035	-0.069	-0.138
L	Long-run	-0.095	-0.190	-0.379
	Short-run	-0.141	-0.282	-0.765

*The effects are based on a 1 per cent increase in the rental rate on R&D capital.

output responds relatively more in the long run to the rental rate on physical capital and because the long-run output elasticities of physical and R&D capital are substantially larger than their short-run counterparts. The demand for labour, however, exhibits a slightly larger (in absolute value) or more elastic output effect in the short run in response to an increase in the rental rate on physical capital. It does so because the output elasticity of labour demand is relatively more elastic in the short run because of the overshooting of labour requirements.

TABLE 6.10
Output effects on factor demands of a change in the wage rate
(in per cent)

Factor demand*		Price elasticity of product demand -1.5	-3	-6
K_p	Long-run	-0.855	-1.710	-3.420
	Short-run	-0.060	-0.120	-0.239
K_r	Long-run	-0.855	-1.710	-3.420
	Short-run	-0.084	-0.167	-0.333
L	Long-run	-0.770	-1.541	-3.082
	Short-run	-0.464	-0.927	-1.853

*The effects are based on a 1 per cent increase in the wage rate.

We turn now to a change in the rental rate on R&D capital (Table 6.9). In this situation the output effects are smaller (in absolute value) than for a change in the rental rate on physical capital predominantly because the cost share of R&D capital is relatively small. In addition, the differences between the long- and short-run effects are not as great. This result occurs because the short-run effects include the marginal adjustment costs of both R&D and physical capital. The latter costs are not inconsequential in comparison with the small R&D capital cost share. Nevertheless, as for a change in the rental rate on physical capital, we still find for the capital inputs that the long-run effects are more pronounced than those obtained in the short run, while the converse occurs for labour because of the differential in output elasticities.

The long-run output effects associated with increases in the wage rate (Table 6.10) are the largest (in absolute value) of the three sets because of the large cost component of labour. The short-run effects are somewhat tempered relative to the capital inputs because of the adjustment costs associated with the capital stocks. The long-run effects for the capital inputs dominate the short-run findings. In addition, we obtain relatively more elastic long-run effects for labour demand. The reason is that the differential between the long- and short-run output elasticities of labour demand is not sufficient to override the marginal adjustment costs incurred in changing the capital input demands in response to an increase in the wage rate.

We are able to compare the compensated own price elasticities (the diagonals in Tables 6.2 and 6.4) to the output effects of physical capital (from Table 6.8), of R&D capital (from Table 6.9), and of labour (from Table 6.10). In the long run the output effects for physical capital are greater (in absolute value) than the compensated own price elasticity for the whole range of price elasticities of product demand. This is not true in the short run, where for relatively inelastic product demand conditions, the compensated own price elasticity of physical capital is greater in absolute value than the output effect. For R&D capital, in both the long and short runs, the compensated own price elasticity is more elastic than the output effects, except for substantially elastic product demand conditions. For labour demand, in the long and short runs, with price elasticities of product demand near the middle of the selected values, the compensated own price elasticity and the output effects are equal. However, as product demand becomes more elastic the output effects become relatively more pronounced.

We can compare the compensated cross price elasticities of factor demands (the off-diagonal elements in Tables 6.2 and 6.4) to the relevant output effects in Tables 6.8 to 6.10. We see that when the rental rate on R&D capital increases, the compensated cross price elasticity and the output effect of physical capital operate in the same direction in both the short and long runs. The same result occurs for R&D capital when the rental rate on physical capital increases. However, when either of the rental rates of the capital inputs increase, the compensated cross price elasticity of labour demand operates in the opposite direction to the output effect in both the short and long runs. This result is due to the fact that labour is a substitute for each of the capital inputs. An increase in the factor price of one of the capital inputs creates an incentive for firms to increase their labour requirements at the existing level of output. Simultaneously, the higher rental rate raises costs and decreases the supply of output, which, in turn, dampens labour demand.

A comparison of the output effects and compensated factor-price elasticities illustrates the relative strengths of the two effects arising from a factor-price change. Another interesting comparison is between the degree to which a factor demand changes as a result of a factor-price change, at the existing level of output, and the degree to which input demands change in response to output expansion at the existing factor price. This is a comparison of the

compensated own factor-price elasticities with the output elasticities (the diagonals in Tables 6.2 and 6.4 with Table 6.7). Clearly, we can observe that output expansion in the long run for the capital inputs generates a substantially greater effect than the compensated own price elasticities (in absolute value). In the short run the output elasticities are still relatively larger. The results are quite different for labour. In the long run the compensated price elasticity dominates (in absolute value) the output elasticity, while in the short run the converse is true.

FACTOR-PRICE ELASTICITIES

The own and cross factor-price elasticities for any input consist of the own and cross compensated factor-price elasticities added to the relevant output effect. Indeed, the short-run own factor-price elasticity of physical capital is found by adding -0.1230 from Table 6.2 to any of the figures in the second row of Table 6.8. The short-run cross factor-price elasticity of physical capital when the rental rate on R&D capital changes is found by adding -0.0083 to the second row of Table 6.9. In a similar fashion we determine the effect on physical capital of a change in the wage rate. Moreover, by performing the same operation with the first column of Table 6.4 and the first rows of Tables 6.8 to 6.10 we can find the long-run factor-price elasticities. These results are presented in Table 6.11. From this table we can observe that for the long run and irrespective of the price elasticity of product demand, the demand for physical capital decreases with an increase in any factor price. This result occurs in the short run for increases in the rental rates. In addition, we see that as product demand becomes more price-elastic the demand for physical capital becomes more price-elastic. In other words, as the product market becomes more competitive firms become more sensitive in adjusting their demands for physical capital to input price changes.

In a fashion similar to that used to obtain the figures in Table 6.11, we can obtain the price elasticities of R&D capital (Table 6.12) and labour (Table 6.13). The results for R&D capital parallel those for physical capital. It is of interest to note that both the rental rate of physical capital and the wage rate generate larger effects on the demand for R&D capital than its own rental rate does. This result emanates from the strength of the output effects of

TABLE 6.11
Factor-price elasticities of physical capital
(in per cent)

Factor price*		Price elasticity of product demand -1.5	-3	-6
w_q	Long-run	-0.844	-1.384	-2.464
	Short-run	-0.188	-0.252	-0.380
w_s	Long-run	-0.153	-0.258	-0.468
	Short-run	-0.033	-0.057	-0.107
w_ℓ	Long-run	-0.503	-1.358	-3.068
	Short-run	0.071	0.011	-1.108

*The elasticities are based on a 1 per cent increase in each of the factor prices.

TABLE 6.12
Factor-price elasticities of R&D capital
(in per cent)

Factor price*		Price elasticity of product demand -1.5	-3	-6
w_q	Long-run	-0.700	-1.240	-2.320
	Short-run	-0.136	-0.226	-0.404
w_s	Long-run	-0.429	-0.534	-0.744
	Short-run	-0.163	-0.197	-0.464
w_ℓ	Long-run	-0.371	-1.226	-2.936
	Short-run	0.092	0.009	-0.157

*The elasticities are based on a 1 per cent increase in each of the factor prices.

changes in the factor prices of physical capital and labour. These latter effects are strong because of the relatively large cost shares of these two factors of production.

The cross price elasticities for labour demand (the first four rows of Table 6.13) serve to signify that the compensated cross price elasticities in both the short and long runs dominate the output effects, unless product demand conditions are quite elastic. Hence the cross price elasticities tend to follow the cross compensated elasticities, except, quite naturally, the former are smaller. The own price elasticities are the result of the compensated own price

TABLE 6.13
Factor-price elasticities of labour
(in per cent)

Factor price*		Price elasticity of product demand -1.5	-3	-6
w_q	Long-run	0.683	0.196	-0.777
	Short-run	0.194	-0.303	-1.296
w_s	Long-run	0.332	0.237	0.048
	Short-run	0.108	-0.033	-0.516
w_ℓ	Long-run	-2.367	-3.138	-4.679
	Short-run	-1.404	-1.867	-2.793

*The elasticities are based on a 1 per cent increase in each of the factor prices.

elasticities and the output effects. These operate in the same direction, and consequently the own price elasticities are negative.

EFFECTS ON INDUSTRIAL R&D EXPENDITURES

Our major concern in this study is with the demand for R&D capital and its rate of accumulation. Therefore, it seems appropriate to translate the results on the price and output effects from percentage terms relating to the demand for R&D capital to dollar magnitudes relating to R&D expenditures (or the current dollar value of the rate of R&D investment). The total R&D capital net of depreciation in millions of 1972 dollars is 1863 for the major R&D investment-undertaking firms in the sample in this study. Applying the average inflation rate of the physical investment (machinery and equipment) deflator, 0.0834, over the period 1972 to 1983 to the R&D capital figure yields an R&D capital of 4843.8 million 1984 dollars for these firms. The present sample of firms accounts for 50 per cent of total industrial R&D expenditures. Thus (4843.8 x 2) = 9687.6 is the industrial R&D capital for Canada in millions of 1984 dollars.

We apply the short-run compensated price elasticities, the output effects, the output elasticity, and the factor-price elasticities to industrial R&D capital to discern the impact or short-run effects on industrial R&D expenditures in Canada. The results are presented in Table 6.14. The first column of the table is derived by multiplying the R&D

capital figure in 1984 by the compensated price elasticities given by the second column in Table 6.2. The second, third, and fourth columns are derived by multiplying 9687.6 by the fourth row of Tables 6.8 to 6.10. The last three columns are derived as the sums of previous columns in the table. The last row of Table 6.14 is derived by multiplying 9687.6 by 0.2216, which is the short-run output elasticity of R&D capital found in Table 6.7. We see from Table 6.14 that a 1 per cent increase in the rental rate on R&D capital decreases R&D expenditures by 12.439 million 1984 dollars at the existing level of output. Once the induced output effects come into play there is a more substantial reduction in R&D expenditures. The decrease in R&D expenditures becomes more pronounced as product demand conditions become more price-elastic.

Changes in the rental rate on physical capital and the wage rate also affect R&D expenditures. Increases in the rental rate on physical capital decrease the expenditures and increases in the wage rate increase the expenditures, at the existing level of output, because R&D capital is a complementary factor of production to physical capital and a substitute for labour. The induced output effects accompanying these two factor-price increases decrease R&D expenditures. This decrease, in turn, enhances the decrease in expenditures associated with the rental rate on physical capital, at existing output levels. The induced output effect of the wage increase operates in the opposite fashion to the price effect at the existing level of output. The former outweighs the latter for quite price-elastic product demand conditions. Lastly, from Table 6.14 we see that a 1 per cent increase in output increases industrial R&D expenditures by 21.313 million dollars in 1984. Hence the decrease in R&D expenditures from a 1 per cent increase in the factor price of R&D capital is smaller than the increase arising from a 1 per cent output increase, except for extremely price-elastic product demand conditions. Thus, in general, output-enhancing effects stimulate R&D expenditures to a greater extent than do factor-price-reducing effects.

The long-run effects on R&D expenditures can be derived in the same fashion as the short-run. First, we note that the long-run R&D capital for the firms in this study is 4563 million 1973 dollars. Adjusting to 1984 dollars by using the inflation rate of 0.0834 and multiplying by 2 yields the long-run total industrial R&D capital of 23,864.2 million 1984 dollars.

TABLE 6.14
Short-run effects on R&D expenditures of factor price and output changes
(in millions of 1984 dollars)

Change in*	Effect at existing output level	Effect of induced output change			Total effect		
		-1.5	-3	-6	-1.5	-3	-6
w_q	-4.573	-8.622	-17.341	-34.585	-13.195	-21.914	-39.158
w_s	-12.439	-3.391	-6.684	-13.369	-15.830	-19.123	-25.808
w_ℓ	17.011	-8.138	-16.178	-32.260	8.873	0.833	-15.249
y						21.313	

*The effects are based on a 1 per cent increase in each of the factor prices and output.

TABLE 6.15
Long-run effects on R&D expenditures of factor price and output changes
(in millions of 1984 dollars)

Change in*	Effect at existing output level	Effect of induced output change			Total effect		
		-1.5	-3	-6	-1.5	-3	-6
w_q	-38.183	-128.867	-257.733	-515.467	-167.050	-295.916	-553.650
w_s	-77.320	-25.057	-50.115	-100.230	-102.377	-127.435	-177.550
w_ℓ	115.503	-204.039	-408.078	-816.156	-88.536	-292.575	-700.653
y						238.59	

*The effects are based on a 1 per cent increase in each of the factor prices and output.

We can now apply the long-run compensated price elasticities, the output effects, the output elasticity, and the factor-price elasticities to the long-run industrial R&D capital to discern the long-run effects on industrial R&D expenditures. The results are presented in Table 6.15, which is constructed in a similar manner to Table 6.14, except long-run magnitudes are used. The magnitudes in Table 6.15 depict the long-run effects on R&D expenditures in millions of 1984 dollars of a permanent 1 per cent increase in each of the factor prices and output level. The long-run effects exceed those found in the short run because the long-run elasticities are larger (in absolute value) and the long-run stock of R&D capital exceeds the short-run level. Once again as in the short run, the effect of a 1 per cent increase in output on R&D expenditures is greater than the effect arising from a 1 per cent increase in the rental rate on R&D capital. Moreover, the difference in these effects is relatively greater compared to the short-run difference.

Besides being able to depict the short- and long-run changes in R&D expenditures from increases in the factor prices and output, we are able to characterize the adjustment in R&D expenditures from the short to long run. We estimated that it takes R&D capital 5.8 years to adjust or 17.3 per cent of the adjustment occurs in a single year.[5] Thus the difference between the long- and short-run magnitudes divided by 5.8 yields the annual adjustment in R&D expenditures associated with each of the factor-price and output changes. These results are presented in Table 6.16. From this table, we see that a permanent 1 per cent increase in the rental rate on R&D capital, at the existing level of output, causes an annual decrease in R&D expenditures of 11.186 million 1984 dollars for 5.8 years. Thus, with an initial decrease of 12.439 million 1984 dollars there is a further annual adjustment for 5.8 years of 11.186 million 1984 dollars leading to a decline of 77.320 million 1984 dollars. In a similar fashion, we can describe the meaning of the other magnitudes in Table 6.16. In particular, a permanent increase in output causes an annual increase in R&D expenditures for 5.8 years of 37.462 million 1984 dollars after the initial increase of 21.313 million 1984 dollars. It is not surprising that since the short- and long-run effects of an output increase are greater than the

5 See the discussion after the estimation results in Chapter 5.

TABLE 6.16

Annual adjustment effects on R&D expenditures of factor price and output changes (in millions of 1984 dollars)

Change in*	Effect at existing output level	Effect of industrial output change			Total effect		
		-1.5	-3	-6	-1.5	-3	-6
w_q	-5.795	-20.372	-41.447	-82.911	-26.527	-47.242	-88.706
w_s	-11.186	-3.736	-7.488	-14.976	-14.922	-18.674	-26.162
w_ℓ	16.981	-33.776	-67.569	-135.155	-16.795	-50.588	-118.174
y						37.462	

*The effects are based on a 1 per cent increase in each of the factor prices and output.

effects of an increase in the rental rate on R&D capital, the annual adjustment associated with increases in the former variable outweighs increases in the rental rate.

SUMMARY OF PRICE AND OUTPUT EFFECTS

In this chapter we have analysed how price and output changes affect the demands for physical and R&D capital and labour for the major R&D investment-undertaking firms in Canada. A number of major conclusions have emerged from the results. First, the demand for R&D capital is responsive to its own rental rate and the factor prices of the other inputs. Second, the price effects generated at the existing level of output production are quite inelastic, with the long-run elasticity exceeding the short-run. Third, the rental rate on R&D capital affects the demands for both physical capital and labour such that the capital inputs complement each other, while R&D capital and labour are substitutes. Fourth, the demand for R&D capital is directly affected by output increases, the long-run effect being greater than the short-run. Indeed, there is no evidence to suggest, even in the long run, that output growth leads to larger than equiproportional growth in R&D capital. Fifth, the output elasticity of the demand for R&D capital is greater than the factor-price elasticity, at the existing level of output, and in general, the former is greater than the latter even when the induced output effect is considered in the factor-price elasticity.

In the short run a 1 per cent increase in the rental rate on R&D capital causes R&D expenditures to decline by about 12.5 million 1984 dollars, at the existing level of output. If the induced output effects are considered, R&D expenditures decline anywhere from about 16 million 1984 dollars to approximately 26 million 1984 dollars, under rather price-elastic product demand conditions. In addition, without the output effects, a 1 per cent increase in the rental rate on physical capital causes R&D expenditures to decline by 4.5 million 1984 dollars, while a 1 per cent increase in the wage rate generates a 17 million 1984 dollar increase in expenditures. The direction of these effects arises from the complementarity of the capital inputs and the substitutability of R&D capital and labour. The induced output effects of changes in these two prices cause R&D expenditures to decline.

In the long run, the decline in R&D expenditures is substantially larger when any one of the capital input prices rise, and the increase is relatively larger than in the short run when the wage rate increases. In the long run, the induced output effects are sufficiently large to cause R&D expenditures to decline when all factor prices increase. Indeed, the combination of the relatively large long-run effects and the fact that R&D capital takes 5.8 years to adjust to its long-run level led us to the result that a 1 per cent increase in the rental rate on R&D capital causes a further annual decline in R&D expenditures for 5.8 years of 11 million 1984 dollars, at the given level of output, and of 15 to 26 million 1984 dollars with the induced output effects. Moreover, even changes in the rental rate on physical capital and the wage rate cause annual adjustments in R&D expenditures, which become quite substantial when the output effects are included.

Finally, a 1 per cent increase in output generates in the short run about a 21.5 million 1984 dollar increase in R&D expenditures and a further annual adjustment for 5.8 years of about 37.5 million 1984 dollars for a long-run increase of 238.5 million 1984 dollars. We found that R&D expenditures respond relatively more to output increases than to decreases in the rental rate of R&D capital.

7

Tax policy and factor demands

The purpose of this chapter is to determine the effects of tax policy on the demands for physical capital (or plant and equipment), R&D capital, and labour for the major R&D investment-undertaking firms in the Canadian economy. In addition, we determine the manner in which R&D expenditures are affected by tax policy and the cost to the government of alternative tax measures.

Three tax policies are considered: the physical investment tax credit, the R&D investment tax credit, and the allowance on incremental R&D investment. Changes in the rates of these alter factor prices, and as a consequence affect the structure of production. An increase in the physical investment tax credit lowers the rental rate on physical capital. This decrease triggers effects on all the factor demands. Increases in the R&D investment tax credit and the allowance decrease the rental rate on R&D capital and thus affect the structure of production.

PHYSICAL INVESTMENT TAX CREDIT

An increase in the physical investment tax credit decreases the rental rate of physical capital by lowering the unit cost of incurring an additional expenditure on plant and equipment investment. Briefly, consider a \$1 expenditure on plant and equipment. The tax reduction on this \$1 expenditure is composed of two elements: a deduction and a credit. The deduction consists of the present value of depreciation deductions net of the tax credit. Thus if $0 < z < 1$ is the present value of depreciation deductions and v is the tax credit rate, then the tax deduction is $\$u_c z(1-v)$, where u_c is the corporate income tax rate. For example, with a depreciation rate of 30 per cent and a discount rate of 15 per

cent, $z = 0.67$. In addition if $u_c = 0.46$ and $v = 0.10$, then the deduction is \$0.28. The tax credit is $v = 0.10$ so the total tax reduction is $\$u_c z(1-v) + \$v = \$0.28 + \$0.10 = \$0.38$. Thus the post-tax unit cost of plant and equipment expenditure is $\$1 - \$0.38 = \$0.62$.

Suppose the tax credit rate doubles from 0.1 to 0.2. The tax reduction increases because the credit increases, but notice that the deduction decreases. Since the credit reduces depreciation deductions, a higher credit rate decreases them even further. Consider the present example. The deduction is $\$u_c z(1-v) = \$0.46(0.67)(1-0.2) = \$0.25$, which is \$0.03 smaller than for the example with the lower tax credit. The total tax reduction, however, is $\$u_c z(1-v) + \$v = \$0.25 + \$0.20 = \$0.45$. This is \$0.07 greater than in the previous case. A doubling of the tax credit increases the tax reduction by 18 per cent and decreases the post-tax unit cost to \$0.55 or by 11 per cent.

The demands for the factors of production depend on (among other things) the array of factor prices. The unit cost of plant and equipment expenditure is part of the rental rate on physical capital. Hence changes in the tax credit affect the unit cost of plant and equipment expenditure and thus the rental rate on physical capital. We have seen (in Chapter 5, following equation (5.11)) that the rental rate on physical capital is

$$w_q = p_p[(\rho+\delta_p)(1-v-d_p) + \psi_p(r_b(1-u_c) - \rho)],$$

where $d_p = u_c(1-v)z$ and z is the present value of depreciation deductions. Thus the term $1-v-d_p$ is the post-tax unit cost of plant and equipment expenditures. This expression is modified to reflect the fact that the price of a unit of physical capital is not \$1 but p_p, that the portion $(\rho+\delta_p)$ of the unit cost accrues to the present period, and that ψ_p of the unit of physical capital is financed by debt. These modifications translate the unit cost of plant and equipment expenditures into the rental rate on physical capital.

An increase of 1 per cent in the physical investment tax credit reduces the rental rate on physical capital by

$$[p_p(\rho+\delta_p)(1-u_c z)v/w_q] \text{ per cent},$$

or 0.181 per cent. In other words, if the tax credit doubles

and the existing rental rate is $1 then the rental rate declines by $0.181.

We are now in a position to determine the effects of changes in the tax credit on factor demands. In the short run we use the first row of Table 6.2, the second, fourth, and sixth rows of Table 6.8, and the second row of Tables 6.11, 6.12, and 6.13 to obtain the compensated price effect, the induced output effect, and the total effect respectively in each of the factor demands. We multiply each of these rows by -0.181. In the long run, we use the first row of Table 6.4, the first, third, and fifth rows of Table 6.8, and the first row of Tables 6.11, 6.12, and 6.13. Once again we multiply these rows by -0.181. The short- and long-run results are presented in Table 7.1. At the existing level of output, a 1 per cent increase in the physical investment tax credit increases the short-run demands for physical and R&D capital by 0.022 per cent and 0.009 per cent respectively. These percentages increase to 0.055 per cent and 0.029 per cent respectively, in the long run. At the existing level of output, labour demand decreases because it is a substitute for physical capital. In the short run, the demand decreases by 0.125 per cent, and in the long run the decline in labour demand becomes more pronounced. The decrease is 0.212 per cent. However, when we consider the induced output effects in both the short and long runs the demands for all the factors increase. The change in output enhances the effects on the capital inputs and modifies the negative impact on labour demand at the existing level of output. It is of interest to note that because the short-run output effects of labour demand exceed those obtained in the long run, labour demand increases in the short run at a relatively more price-inelastic product demand than in the long run.

R&D INVESTMENT TAX CREDIT

The general analysis pertaining to the physical investment tax credit also applies to this part of the chapter. The unit cost of $1 of R&D expenditures is reduced by the tax deduction arising from the expensing of the $1 expenditure, the tax credit, and the incremental allowance associated with the expenditure.[1] Increases in the investment tax

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1 The implications with respect to the post-tax unit cost of R&D expenditures were fully discussed in Chapter 3.

TABLE 7.1
Effects of physical investment tax credit on factor demands
(in per cent)

Factor demand*		Effect at existing output level	Effect of induced output change			Total effect		
			-1.5	-3	-6	-1.5	-3	-6
K_p	Long-run	0.55	0.098	0.196	0.391	0.153	0.251	0.446
	Short-run	0.22	0.012	0.023	0.047	0.034	0.045	0.069
K_r	Long-run	0.029	0.098	0.196	0.391	0.127	0.225	0.420
	Short-run	0.009	0.016	0.032	0.065	0.025	0.041	0.074
L	Long-run	-0.212	0.088	0.176	0.352	-0.124	-0.036	0.140
	Short-run	-0.125	0.090	0.180	0.360	-0.035	0.055	0.235

*The effects are based on a 1 per cent increase in the physical investment tax credit rate.

TABLE 7.2
Effects of R&D investment tax credit on factor demands
(in per cent)

Factor demand*		Effect at existing output level	Effect of induced output change			Total effect		
			-1.5	-3	-6	-1.5	-3	-6
K_p	Long-run	0.004	0.009	0.018	0.035	0.013	0.022	0.039
	Short-run	0.001	0.002	0.004	0.008	0.003	0.005	0.009
K_r	Long-run	0.027	0.009	0.018	0.035	0.036	0.045	0.062
	Short-run	0.011	0.003	0.006	0.012	0.014	0.017	0.023
L	Long-run	-0.036	0.008	0.016	0.032	-0.028	-0.020	-0.004
	Short-run	-0.021	0.012	0.024	0.064	-0.009	0.003	0.043

*The effects are based on a 1 per cent increase in the R&D investment tax credit rate.

credit rate reduce the post-tax unit cost of R&D expenditures, and as a consequence the rental rate on R&D capital. The rental rate on R&D capital (see the discussion in Chapter 5 following equation (5.11)) is

$$w_s = p_r[\rho+\delta_r)((1-u_c)(1-v) - d_r) + \psi_r(r_b(1-u_c) - \rho)].$$

Thus a 1 per cent increase in the R&D investment tax credit reduces the rental rate by

$$-[p_r(\rho+\delta_r)(1-u_c)v/w_s] \text{ per cent,}$$

or 0.084 per cent. In other words, if the tax credit rate doubles and the existing rental rate is $1, then the rental rate decreases by $0.084. The percentage decrease in the rental rate on R&D capital is substantially below that on physical capital because the effective R&D investment tax credit rate is much smaller than the effective rate for physical investment. Indeed, the effective R&D investment tax credit rate is only around half the statutory rate of 0.10. Limitations on the ability of firms to use the R&D investment tax credit create a situation where credits are unutilized and the effective credit rate falls below the statutory rate.[2]

The effects on factor demands of a change in the R&D investment tax credit rate are given in Table 7.2. This table is constructed in the following manner. The short-run effects in column 1 are obtained by multiplying the second row of Table 6.2 by -0.084. The second, third, and fourth columns are obtained by multiplying the second, fourth, and sixth rows of Table 6.9 by -0.084. The last three columns are found by adding the first column to each of the second, third, and fourth columns of Table 7.2. In the long run, we use the second row of Table 6.4 and the first, third, and fifth rows of Table 6.9.

We can observe from Table 7.2 that the pattern of the effects is the same as when the physical investment tax credit rate increased. However, now the total effects are much smaller (in absolute value). There are two reasons. First, the output effects associated with changes in the rental rate on R&D capital are relatively smaller than those associated with the rental rate on physical capital, the reason being that physical capital comprises a much larger share of total costs. Second, the effective R&D investment

2 In Chapter 3 we discussed the severe problem of unutilized R&D investment tax credits.

tax credit rate is substantially less than the effective physical investment tax credit rate. Indeed, we found that a 1 per cent increase in the latter rate decreased the rental rate on physical capital by 0.181 per cent, whereas for the credit on R&D capital, the rental rate declined by only 0.084 per cent.

Since the effective R&D investment tax credit is at about one-half the statutory rate, if we double the magnitudes in Table 7.2 then we can obtain the effects on factor demands when the R&D investment tax credit rate equals the statutory rate of 0.10. In this case a 1 per cent increase in the credit rate decreases the rental rate on R&D capital by 0.168 per cent (or 2 x 0.84 per cent).

We can interpret the difference between the effects at the effective and statutory R&D investment tax credit rates in the following manner. In the short run, if the government introduced policy changes such that the effective tax credit rate became equal to the statutory rate then the demand for R&D capital would increase by 1.1 per cent at the existing level of output and by 1.4 to 2.3 per cent in total, depending on the price elasticity of product demand conditions. Next if the statutory credit rate increases from 0.10 to 0.20 then the demand for R&D capital increases by 2.2 per cent at the existing level of output and by 2.8 to 4.6 per cent in total. Thus the total effect in the short run of the two tax policies is to increase the demand for R&D capital by a range from 4.2 per cent to 6.9 per cent. In the long run, the total effect of the combination of erasing the non-utilization of R&D credits and doubling the statutory credit rate ranges from 7.2 to 12.4 per cent.

INCREMENTAL R&D INVESTMENT TAX ALLOWANCE

The previous tax credits had at least one common aspect. They were based on the investment expenditure in the current year. The incremental tax allowance is based on the difference between the current R&D expenditures and the average over the past three years. If current expenditures exceed the three-year moving average, then γ_r of the excess is added to the allowable tax deductions pertaining to R&D investment. For example, with $1 in current R&D expenditures, which also represents the excess over the average of the past three years, there is a tax reduction of $$(1+\gamma_r)u_c$. The post-tax unit cost of the R&D expenditures is $$[1 - (1+\gamma_r)u_c]$. Thus,

with a corporate income tax rate of 0.46, and an incremental R&D investment tax allowance rate of 0.5, the tax reduction on a $1 expenditure, which is also the excess over the base, is equal to $0.69, and the post-tax unit cost is $0.31.

To determine the impact of a change in the incremental R&D investment tax allowance rate on factor demands consider, once again, the rental rate on R&D investment. From

$$w_s = p_r[\rho+\delta_r)(1-u_c)(1-v) - d_r) + \psi_r(r_b(1-u_c) - \rho)],$$

the tax allowance rate affects the rental rate through d_r.

By definition,

$$d_r = u_c\gamma_r\int_0^\infty e^{-\rho\tau}\mu_r(\tau)d\tau$$

(see the discussion in Chapter 5 after equation (5.8)). Under the tax legislation relevant to this study, the time period used in determining d_r is the current and three previous periods. Thus the current period's R&D expenditures enter into the calculation of the present tax allowance, and into the computation for the following three years. They do so because the base of the allowance rate is the excess of the current expenditures over the average of the previous three years. Thus we can define

$$\mu_r^n = \sum_{\tau=0}^{3}\mu_r(\tau)/(1+\rho)^\tau,$$

where $\mu_r(0) = 1$, $\mu_r(\tau) = -1/3$ for $\tau = 1,2,3$, and so

$$w_s = p_r[(\rho+\delta_r)((1-u_c)(1-v) - u_c\gamma_r\mu_r^n) + \psi_r(r_b(1-u_c) - \rho)].$$

Now we find that a 1 per cent increase in the tax allowance rate decreases the rental rate by

$$-[p_r(\rho+\delta_r)u_c\mu_r^n\gamma_r/w_s] \text{ per cent},$$

or by 0.066 per cent. Thus given a doubling of the incremental R&D investment tax allowance rate and an existing rental rate of $1, the rental rate declines by $0.066.

The effects on factor demands of a change in the incremental R&D investment tax allowance rate are given in Table 7.3. This table is constructed in an identical fashion to Table 7.2 except the multiplying number is -0.066. From Table 7.3, we see that these effects are the smallest (in absolute value) of the varoius tax incentive effects we have

TABLE 7.3

Effects of incremental R&D investment tax allowance on factor demands (in per cent)

Factor demand*	Effect at existing output level	Effect of induced output change			Total effect		
		-1.5	-3	-6	-1.5	-3	-6
K_p Long-run	0.003	0.007	0.014	0.028	0.010	0.017	0.031
Short-run	0.001	0.002	0.003	0.006	0.003	0.004	0.007
K_r Long-run	0.021	0.007	0.014	0.028	0.028	0.035	0.049
Short-run	0.009	0.002	0.005	0.009	0.011	0.014	0.018
L Long-run	-0.028	0.006	0.013	0.025	-0.022	-0.015	-0.005
Short-run	-0.017	0.009	0.019	0.050	-0.008	0.002	0.033

*The effects are based on a 1 per cent increase in the incremental R&D investment tax allowance rate.

considered in this chapter. In addition, the effects are close in magnitude to the R&D investment tax credit elasticities pertaining to the effective tax credit rate. Hence an allowance, which by definition only decreases taxable income, and is based on incremental R&D expenditures, exerts almost the same impact as the effective tax credit, based on total R&D expenditures.

R&D EXPENDITURES AND TAX-POLICY COSTS

The effect on R&D expenditures of the three tax incentives we have considered can be seen in Tables 6.14, 6.15, and 6.16. To derive short-run effects on R&D expenditures we use Table 6.14. By multiplying the first row of this table by -0.181, which is the decrease in the rental rate on physical capital for a 1 per cent increase in the physical investment tax credit rate, we compute the increase in R&D expenditures, valued in millions of 1984 dollars, associated with this policy change. The short-run effects associated with increases in the effective and statutory R&D investment tax credit rates and the incremental R&D investment allowance rate are obtained by multiplying the second row of Table 6.14 by -0.084, -0.168, and -0.066 respectively. The short-run effects on R&D expenditures are presented in Table 7.4.

At the existing level of output, increases in the statutory R&D investment tax credit rate exert the largest impact on R&D expenditures. The next largest effect is related to the effective R&D investment tax credit rate, while the physical investment tax credit rate and the incremental R&D allowance rate exert almost the same effect. It is interesting to note that the problem of unutilized R&D investment tax credits is so severe that, even at the existing level of output, the (effective) physical investment tax credit exerts almost the same effect as the effective R&D investment tax credit, in spite of the relatively small short-run cross price effects between physical and R&D capital, at the existing level of output (see the second column in Table 6.2).

We can also observe from Table 7.4 that the output effects on R&D expenditures of an increase in the physical investment tax credit rate dominate all other output effects. This situation arises because the cost share of physical capital is substantially larger than that of R&D capital. It is the former that is part of the output effects for the tax policy which affects the rental on physical capital,

TABLE 7.4
Short-run effects on R&D expenditures of tax-policy changes
(in millions of 1984 dollars)

Tax policy*	Effect at existing output level	Effect of induced output change			Total effect		
		-1.5	-3	-6	-1.5	-3	-6
Physical investment tax credit	0.828	1.561	3.139	6.260	2.389	3.967	7.088
R&D investment tax credit (effective rate)	1.045	0.285	0.561	1.123	1.330	1.606	2.168
R&D investment tax credit (statutory rate)	2.090	0.570	1.122	2.246	2.660	3.212	4.336
Incremental R&D investment tax allowance	0.821	0.224	0.441	0.882	1.045	1.262	1.703

*The effects are based on a 1 per cent increase in each of the credit and allowance rates.

and the latter that is part of the output effects for tax policies which affect the rental rate on R&D capital. Because the output effects of increases in the physical investment tax credit rate are so large, the total effect of this tax incentive dominates all others.

The long-run effects on R&D expenditures of the tax-policy changes are presented in Table 7.5, and Table 7.6 contains the annual adjustment effects as R&D expenditures approach their long-run level. The first row of Table 7.5 is derived by multiplying the first row of Table 6.15 by -0.181; the other rows are derived by multiplying the second row in Table 6.15 by -0.084, -0.168, and -0.066. Table 7.6 is derived in the same fashion, but Table 6.16 is used. The pattern of effects both in the long run and in the adjustment to the long run resembles the pattern found in the short run. Thus we see that the problem of unutilized R&D investment tax credit is important in terms of limiting the effectiveness of increases in the credit rate stimulating R&D expenditures. Indeed the relative difference between the effects at the statutory and effective rates is two to one and the effect of increases in the allowance (based on incremental R&D expenditures) is almost as large as the impact from the effective tax credit rate. In addition, tax policy incentives for physical investment tend to be an important stimulant to R&D expenditures because of the complementary nature of the capital inputs in production, in both the short and long runs, and of the adjustment process.

The tax incentives affect the structure of production, in general, and stimulate R&D expenditures, in particular. To undertake these policy measures the government must incur costs in terms of forgone tax revenues. We would like to know the costs of the various policies under consideration. In addition, determining the costs would permit us to obtain a better handle on the relative effectiveness of the physical investment tax credit in stimulating R&D expenditures compared to the R&D investment tax credit and allowance. A 1 per cent increase in the physical investment tax credit rate costs the government relatively more than a 1 per cent increase in the other credit and allowance rates, because physical capital comprises a relatively larger proportion of production costs than does R&D capital. That is, there is a larger production cost reduction from a 1 per cent increase in the former rate than in the latter rate. Therefore the firms receive a relatively larger subsidy from the government. Thus the relative effectiveness in stimulating R&D

TABLE 7.5
Long-run effects on R&D expenditures of tax-policy changes (in millions of 1984 dollars)

Tax policy*	Effect at existing output level	Effect of induced output change			Total effect		
		-1.5	-3	-6	-1.5	-3	-6
Physical investment tax credit	6.911	23.325	46.650	93.300	30.236	53.561	100.211
R&D investment tax credit (effective rate)	6.495	2.105	4.210	8.419	8.600	10.705	14.914
R&D investment tax credit (statutory rate)	12.990	4.210	8.420	16.838	17.200	21.410	29.828
Incremental R&D investment tax allowance	5.103	1.654	3.308	6.615	6.757	8.411	11.718

*The effects are based on a 1 per cent increase in each of the credit and allowance rates.

TABLE 7.6
Annual adjustment effects on R&D expenditures of tax-policy changes
(in millions of 1984 dollars)

Tax policy*	Effect at existing output level	Effect of induced output change			Total effect		
		-1.5	-3	-6	-1.5	-3	-6
Physical investment tax credit	1.049	3.752	7.502	15.007	4.801	8.551	16.056
R&D investment tax credit (effective rate)	0.940	0.314	0.629	1.258	1.254	1.569	2.198
R&D investment tax credit (statutory rate)	1.880	0.628	1.258	2.516	3.080	3.138	4.396
Incremental R&D investment tax allowance	0.738	0.247	0.494	0.988	0.985	1.232	1.726

*The effects are based on a 1 per cent increase in each of the credit and allowance rates.

expenditures is appropriately measured on a per dollar basis of government cost, rather than in terms of the magnitude of R&D expenditures.

First consider a 1 per cent increase in the physical investment tax credit rate. This generates a decrease in costs of 0.059 per cent.[3] Total costs are 177.4 million 1972 dollars at the mean of the sample of data in this study. Grossing up by the average inflation rate of 0.0834 and by the number of firms (27), and doubling this figure in order to obtain the costs pertaining to all firms engaged in undertaking R&D investment, the total cost, for all firms, is 250.559 million 1984 dollars.[4] Thus total costs decline by 14.783 million 1984 dollars. Hence if the government increases this tax credit rate, the total increase in R&D expenditures ranges from $0.107 to $0.48 per dollar of lost tax revenue, and about $0.06 at the existing level of output. These figures are obtained by dividing the first row in Table 7.4 by 14.783. Therefore, because of the complementarity of the capital inputs in the production process, a policy measure designed to stimulate physical investment also causes firms to increase R&D expenditures.

Next consider a 1 per cent increase in the R&D investment tax credit rate. The decline in costs is 0.005 per cent which is 1.253 million 1984 dollars. Dividing the second row of Table 7.4 by this figure yields $0.83 of R&D expenditures per dollar of lost tax revenue, at the existing level of output. The total effect ranges from $1.06 to $1.73 of R&D expenditures per dollar of lost tax revenue.[5]

A 1 per cent increase in the incremental R&D investment tax allowance causes costs to decline by 0.004 per cent or

3 Equation (5.13) defines the change in costs for an increase in the rental rate on physical capital. By multiplying both sides of this equation by the ratio of the rental rate on physical to total costs, we obtain the percentage change in costs for a 1 per cent increase in the rental rate. If we multiply this magnitude by -0.181, we obtain the percentage decline in costs for a 1 per cent increase in the physical investment tax credit rate.

4 This is the same procedure we used to obtain the R&D capital stock in millions of 1984 dollars.

5 These figures are also applicable to the statutory R&D investment tax credit rate, since this rate decreases total costs by twice as much as the effective rate and generates twice as much R&D expenditures.

1.003 million 1984 dollars. Thus, at the existing level of output, about $0.82 of R&D expenditures is generated per dollar of lost tax revenue and the total effect ranges from $1.04 to $1.70. These figures are given in Table 7.7.

R&D TAX INCENTIVES AND POLICY PROPOSALS

We have estimated the impact of changes in the physical and R&D investment tax credit rates and in the incremental R&D investment tax allowance rate. Recently, specific proposals have been introduced with respect to the tax incentives directed towards R&D expenditures. These proposals (see 'Research and Development Tax Policies: A Paper for Consultation' [Department of Finance, April 1983]) have centred on three aspects: (1) increasing the utilization of the R&D investment tax credit, (2) doubling the R&D investment tax credit rate, (3) abolishing the incremental R&D investment tax allowances. The evidence that we have accumulated permits us to determine the effect of each of these government policy changes on factor demands and costs.

With respect to the credit utilization issue, four measures have been proposed. It was recommended that:

1 The limit on the amount of tax credit a firm can claim in any one year be removed.
2 Longer periods over which unused credits can be carried forward or backward be introduced.
3 Transferring of unused tax credits of a corporation to persons purchasing new equity issues of the corporation be permitted.
4 The government provide a portion of unused credits in cash to non-taxable corporations and unincorporated businesses.

Let us assume the four policy measures will be successful in closing the gap between the effective and statutory R&D investment tax credit rates. The consequence of increasing the utilization of the tax credits is to raise the effective rate from 0.05 to 0.10. From the second row of Table 7.4, we see that, at the existing level of output, R&D expenditures increase by 104.5 million 1984 dollars. The total effect ranges from 133 to 216.8 million 1984 dollars. The cost to the government in terms of lost tax revenue is 125.3 million 1984 dollars. The third row of Table 7.4 shows us that a doubling of the statutory credit rate generates 209 million 1984 dollars, at the existing level of output, and leads to a total effect ranging from 266 to 433.6 million 1984

TABLE 7.7
R&D expenditures per dollar of lost tax revenue
(in 1984 dollars)

Tax policy	Effect at existing output level	Effect of induced output change			Total effect		
		-1.5	-3	-6	-1.5	-3	-6
Physical investment tax credit	0.06	0.11	0.21	0.42	0.17	0.27	0.48
R&D investment tax credit*	0.83	0.23	0.45	0.90	1.06	1.28	1.73
Incremental R&D investment tax allowance	0.82	0.22	0.44	0.88	1.04	1.26	1.70

*The figures in this row are applicable to both the effective and statutory rates.

TABLE 7.8
Impact of policy proposals (in millions of 1984 dollars)

	R&D expenditures		
	Effect at existing output level	Range of total effect	Government cost
Increasing tax credit utilization	104.5	133.0 to 216.8	125.3
Doubling tax credit rate	209.0	266.0 to 433.6	250.6
Eliminating tax allowance	-82.1	-104.5 to -170.3	-100.3
Net impact	231.4	294.5 to 480.1	275.6

dollars. The cost to the government of this policy is 250.6 million 1984 dollars. The last policy concerns the elimination of the tax allowance based on incremental R&D expenditures. In this case, from the fourth row of Table 7.4, R&D expenditures decrease, at the existing level of output, by 82.1 million 1984 dollars. The total effect shows a decline ranging from 104.5 to 170.3 million 1984 dollars. The elimination of the allowance saves the government 100.3 million 1984 dollars. These figures are presented in Table 7.8.

The net effect of the policy proposals is to increase R&D expenditures by 231.4 million 1984 dollars, at the existing level of output. The net impact, inclusive of the induced output effects, ranges from 294.5 to 480.1 million 1984 dollars at a net cost of 275.6 million 1984 dollars. Therefore, the government generates per dollar of lost tax revenue about $0.84 of R&D expenditures, at the existing level of output, and $1.07 to $1.74 of R&D expenditures, when the total effects of each policy measure are considered.

8

Financial capital structure and factor demands

It is often argued that R&D investment is financed relatively more through internal funds and share issues rather than debt. This mix is the converse of the nature of financing physical investment. In this study, we have developed an intemporal cost-minimizing model which admits the influence of the finacial capital structure on factor demands. In this chapter the nature of this influence and also the effects of interest-rate changes on the demands for physical and R&D capital, labour requirements, and R&D exependitures are investigated.

FINANCING PROPORTIONS AND INTEREST RATES

The proportion of financing conducted by debt relative to equity affects the unit costs of physical and R&D capital and therefore the prices firms pay for the use of these factors of production. We have estimated (see Table 5.1) that 47 per cent of physical capital is financed by debt, while only 9 per cent of R&D capital is funded in this manner.[1] The reasons for this difference can be based on the relative risks associated with R&D projects. First, the outcome of R&D investment is uncertain and therefore (in a situation where default is costly) firms may not be able to borrow adequate funds to finance development of a new product or process. Indeed, it may be that only firms generating a sub-

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1 In Table 5.1 the parameters ψ_p and ψ_r represent the debt-financing proportions of physical and R&D capital respectively.

stantial flow of funds can support a sizeable R&D investment effort.

Second, the willingness and ability of firms to go to the financial capital markets depend on the perception of the risks associated with R&D investment. For secretive processes which could not be reasonably protected by patents, a firm may be unwilling to reveal any more than a small part of the process to the capital market. In addition, the market may not be able to evaluate the risks associated with a proposed process when the expertise is distributed only among the personnel of the firm.

An increase in the interest rate affects the rental rates on physical and R&D capital, and therefore the structure of production is altered. Indeed, the interest rate on corporate debt, through its effect on both rental rates, affects the demand for each factor of production. Thus, the demand for each input is influenced by the debt-financing composition of both types of capital and by the elasticities associated with both rental rates.[2] Therefore, as the factor price effects and the debt-financing composition for both capital inputs become equalized, then the interest rate effects on physical and R&D capital become equalized.

The interest rate effects are presented in Table 8.1. We can observe that the effects on R&D capital and physical capital are not substantially different, especially when the total effect is considered and not just at the existing level of output. The result arises because the rental rate on physical capital affects the demand for R&D capital significantly more than the reverse, which overcomes the differential in the composition of debt financing.

The influence of the interest rate on labour demand is quite interesting. At the existing level of output, an increase in the rate raises labour demand because this factor is a substitute for both capital inputs. However, as the induced output effects come into play they generate decreases in labour demand, and for very price-elastic product demand conditions labour demand also decreases with an increase in the interest rate.

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2 This can be seen from the formulas for the interest-rate effects given at the bottom of Table 8.1. They are obtained by differentiating the system of factor demand equations (which are the estimated equations (5.18), (5.19), and (5.20)) with respect to the interest rate on corporate bonds.

TABLE 8.1
Interest-rate effects on factor demands (in per cent)

Factor demand*		Effect at existing output level	Range of total effect
K_p^{**}	Long-run	-0.099	-0.278 to -0.815
	Short-run	-0.039	-0.062 to -0.129
K_r	Long-run	-0.078	-0.256 to -0.793
	Short-run	-0.026	-0.057 to -0.166
L	Long-run	0.404	0.243 to -0.240
	Short-run	0.238	0.070 to -0.451

*The effects are based on a 1 per cent increase in the interest rate.

**The formulas to determine these effects are

$$e_{jb}^{ih} = e_{jq}^{ih}\psi_p r_b(1-u_c)p_p/w_q + e_{js}^{ih}\psi_r r_b(1-u_c)p_r/w_s,$$

where the superscript i = L, s stands for long- and short-run, the superscript h = c,t stands for compensated and total price elasticity, the subscript j = p,r,ℓ stands for physical capital, R&D capital, and labour.

INTEREST-RATE CHANGES AND R&D EXPENDITURES

Using the results given in Table 8.1 and recalling that R&D capital was 9687.6 million dollars in 1984 and the long-run R&D capital was 23,864.2 million dollars in 1984, we can calculate the changes in R&D expenditures associated with increases in the interest rate. The results are given in Table 8.2. We see that, at the existing level of output, a 1 per cent increase in the interest rate causes R&D expenditures to decline by 2.5 million dollars in 1984. The decrease in expenditures from the total effect ranges from 5.5 to 14.5 million dollars in 1984, as a result of a 1 per cent increase in the corporate bond interest rate. If we are concerned with the long run, then the decline in R&D expenditures is more pronounced. At the existing level of output, expenditures decrease by about 18.5 million dollars, while the total effect in the long run causes a decrease ranging from 61 to 188.5 million dollars.

TABLE 8.2
Interest-rate effects on R&D elasticities
(in millions of 1984 dollars)

	Effect at existing output level	Effect of induced output change			Total effect		
		-1.5	-3	-6	-1.5	-3	-6
Long-run*	-18.614	-42.479	-84.959	-169.918	-61.093	-103.573	-188.532
Short-run	-2.519	-3.003	-6.007	-12.014	-5.522	-8.526	-14.533

*The effects are based on a 1 per cent increase in the interest rate.

9

Conclusion

This study leads to three general classes of conclusions: first, the factor substitution, output expansion, and capital adjustment effects; second, the tax incentive effects; and third, the financial capital structure effects. The first set of results relates to the determinants of the structure of production and investment of the major R&D investment-undertaking firms in Canada. Specifically, we found that physical and R&D capital were complementary factors, while each was a substitute for labour.

The demand for R&D capital depended on all three factor prices and output. We estimated that a 1 per cent increase in the rental rate on R&D capital decreased the demand for R&D capital by 0.12 per cent in the short run, and by 0.32 per cent in the long run, when the level of output production does not change. Once the output effects are considered, the range of the decrease in the short run is 0.16 to 0.46 per cent depending on the degree of competitiveness in the product market; the greater the degree of competition, the larger is the decline in R&D capital. In general, the output effects dominate the factor-price effects such that when output alone increases by 1 per cent the demand for R&D capital increases by 0.22 per cent in the short run and by almost 1 per cent in the long run. Thus R&D capital in the long run increases in proportion to output. There does not seem to be any evidence that demand increases more then equiproportionately to output.

The accumulation of R&D capital is affected by factor-price and output changes. We estimated that a 1 per cent increase in the rental rate on R&D capital caused R&D expenditures to decline by 12.5 million dollars in 1984, at the existing level of output. If the induced output effects

associated with the factor-price rise are considered then the decrease ranges from 16 to 26 million dollars in 1984. In addition, we found that changes in the prices of physical capital and labour exerted pressure on R&D expenditures. A 1 per cent increase in the rental rate on physical capital caused R&D expenditures to decline by 4.5 million dollars in 1984, at the existing level of output, and to decline by 13 to 39 million dollars when output decreases in response to the higher factor cost. Also a 1 per cent increase in the wage rate generated 17 million more dollars in 1984 for R&D expenditures. However, as output falls with the higher wage, the increase in R&D expenditures falls to about 9 million dollars, and if the product market is quite competitive R&D expenditures may even decrease by 15 million dollars in 1984. These results, encompassing the induced output effects, indicate that output changes exert a great influence on R&D expenditures. Indeed a 1 per cent increase in output generates as much as 21 million dollars more R&D expenditures in 1984.

In this study we estimated that firms take time to adjust both their R&D and physical capital stocks. Physical capital takes about four years to adjust, with about 26 per cent of the adjustment occurring in a single year. R&D capital takes longer. The process takes about six years, with 17 per cent of the adjustment occurring in a single year. It is also of interest to note that the adjustment in physical capital hastens the adjustment in R&D capital. The converse is true as well. Therefore, the capital inputs are complements both in the production and in the capital adjustment processes.

Turning to the second set of conclusions, we found that the tax incentives on physical and R&D investment do affect the structure of production. A 1 per cent increase in the tax credit rate on physical investment in the short run generated a 0.022 per cent increase in physical capital, at the existing level of output, and when output effects were considered the range of increase was 0.034 to 0.069 per cent. In the long run, the range of increase in physical capital was 0.153 to 0.446 per cent, with an increase of 0.055 per cent at the existing level of output. Physical and R&D capital are complementary factors, which means that an increase in the tax credit rate on physical capital generates an increase in the demand for R&D capital. In the short run, at the existing level of output the increase is about 0.01 per cent. However, once the induced output effects are

considered, the rise in demand ranges from 0.02 to 0.075 per cent. In the long run the increases are much larger, ranging from 0.137 to 0.420 per cent.

Labour demand is also affected by the tax credit on physical investment. Since labour and physical capital are substitutes, at the existing level of output labour demand declines in response to a 1 per cent increase in the tax credit. In the short run the decline is 0.125 per cent and in the long run 0.212 per cent. However, the induced output effects associated with the increase in the tax credit cause labour demand to rise. These effects tend to offset the decrease in demand when output does not expand. Thus, in the short run the net effect on labour ranges from a decrease of 0.035 per cent to an increase of 0.235 per cent, while in the long run the range is from a decrease of 0.124 per cent to an increase of 0.140 per cent.

The increase in the demand for R&D capital associated with a higher tax credit on physical investment implies that R&D expenditures must rise. We calculated that at the existing level of output, R&D expenditures would increase by 0.83 million dollars in 1984 for a 1 per cent increase in the tax credit rate. The total effect ranges from 2.4 to 7 million dollars in 1984. The cost to the government of increasing the tax credit by 1 per cent is 14.78 million dollars in 1984. Thus the increase in R&D expenditures per dollar cost to the government for a 1 per cent in the credit rate on physical capital ranges from \$0.11 to \$0.48.

An increase in the R&D investment tax credit rate affects the structure of production and R&D expenditures. Indeed, an increase in this credit rate generates the same directional shift in factor demands as an increase in the rate on physical investment, although the magnitudes are different. A 1 per cent increase in the R&D investment tax credit rate causes the demand for R&D capital to increase by 0.011 per cent in the short run and by 0.027 per cent in the long run, at the existing level of output. The total effect ranges from 0.014 to 0.023 per cent in the short run and from 0.036 to 0.062 per cent in the long run. Moreover, the 1 per cent increase in the tax credit rate causes the demand for physical capital to increase by 0.003 to 0.009 per cent in the short run and 0.013 to 0.039 per cent in the long run. Labour demand may increase or decrease in the short run in response to a higher credit rate, depending on the degree of competitiveness in the product market. As the product market becomes more competitive labour demand variations

range from a decline of 0.009 per cent to an increase of 0.043 per cent. In the long run, labour demand generally declines in response to an increase in the tax credit on R&D investment, but the effects are not very large, varying from 0.028 to 0.004 per cent for relatively more competitive product markets.

The results of an increase in the tax credit rate on R&D investment pertain to the effective rate utilized by the major firms undertaking R&D investment. Indeed, we calculated that the effective credit rate was one-half the statutory rate of 0.10. Therefore the underutilization of the R&D credits was a severe problem. Little would be gained by government policy which increased the statutory rate without solving the utilization problem. However, if the utilization issue could be overcome, thereby eliminating the gap between the effective and statutory rates, the impact of an increase in the tax credit rate would be twice as large as that found for an increase in the underutilized credit rate.

R&D expenditures respond to increases in the tax credit rate. A 1 per cent increase in the effective tax credit rate generates 1.05 million dollars more R&D expenditures in 1984, at the existing level of output. Once the output effects come into force the increase in R&D expenditures ranges from 1.33 to 2.17 million dollars in 1984. The 1 per cent increase in the effective rate costs the government 1.25 million dollars in 1984. Therefore, at the existing level of output $0.83 of R&D expenditures is generated per dollar cost to the government, and with an expanding output the range is $1.06 to $1.73.

The effects on R&D expenditures and the structure of production generated by an increase in the incremental R&D investment tax allowance are almost the same as those generated by an increase in the effective tax credit rate. This result further highlights the severity of the underutilization problem of R&D investment credits, because the allowance is based only on the excess of current R&D expenditures over the average of the previous three years, while the credit is based on total current R&D expenditures. We estimate that a 1 per cent increase in the incremental R&D investment tax allowance caused R&D expenditures to increase by 0.821 million dollars in 1984, at the existing level of output, and resulted in a total increase of 1.05 to 1.70 million dollars in 1984. The cost to the government of this 1 per cent increase was slightly more than 1 million dollars in 1984. Thus the per dollar cost to the government when the

allowance rate rises is about the same as when there is an increase in the effective tax credit rate.

Recently policy proposals have been introduced by the government which aim at eliminating the utilization problem of R&D investment tax credits, doubling the statutory credit rate (which now also becomes the effective tax credit rate), and eliminating the incremental allowance. We estimated that the net effect of these policies was to generate 231.4 million dollars in R&D expenditures in 1984, at the existing level of output, and the total effect (when output increases) ranged from 294.5 to 480.1 million dollars, at a cost to the government of 275.6 million dollars in 1984.

The last set of conclusions relate to the financing composition of physical and R&D capital and the effect of increases in interest rates on the structure of production. In this study it was estimated that additions to R&D capital are financed 9 per cent by debt and 91 per cent by both internal funds and share issues. Since the firms in the sample issue shares relatively infrequently, the majority of the equity financing is conducted through internal funds. However, for physical capital, 47 per cent of additions are financed by debt. Thus there is a significant difference between the financing modes of the two types of capital.

Interest-rate changes affect the structure of production. The effects on the demands for physical and R&D capital are not dissimilar. At the existing level of output, when the corporate bond interest rate increases by 1 per cent the demand for R&D capital decreases by about 0.03 per cent in the short run and by 0.08 per cent in the long run. The total effect ranges from a decrease of 0.06 to 0.17 per cent in the short run and of 0.26 to 0.80 per cent in the long run. Labour demand increases in response to a higher interest rate at the existing level of output production, both in the short and long runs. Yet as the output effects come into force even labour demand tends to decrease.

In 1984 a 1 per cent increase in the interest rate caused R&D expenditures to decline by 2.5 million dollars, at the existing level of output, and generated a total effect which ranged from 5.5 to 14.5 million dollars. In general, the effects of a rising interest rate on factor demands and R&D expenditures were less than those obtained from growing product demand (or in other words output production). Thus the depressing influences of rising interest rates on R&D expenditures can be overcome by expanding product demand.

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31 Research and Development, Tax Incentives, and the Structure of Production and Financing

JEFFREY I. BERNSTEIN

As Canada's rate of productivity growth continues to slow and competitiveness from foreign producers continues to increase, a great deal of interest has come to focus on the sources of input growth. It is generally recognized that technological change exerts a positive and significant influence on output growth, and a major component of this technological development is research and development (R&D) investment.

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Bernstein's study has significant implications for the Canadian manufacturing industry, for government tax policy, and, ultimately, for the Canadian economy's ability to compete in world markets.

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University of Toronto Press

ISBN 0-8020-6629-1